PRINCIPLES OF NAVAL ORDNANCE AND GUNNERY

Prepared by

BUREAU OF NAVAL PERSONNEL

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PREFACE

The principal purpose of this book is to serve as a classroom training text for NROTC and OCS students. It will also be useful to weapon department officer personnel as a reference and as a convenient general reference in ordnance and gunnery for others.

This text is not intended to supersede or supplant official publications of the Chief of Naval Operations, the Naval Ordnance Systems Command, the Naval Ship Systems Command, or the Bureau of Naval Personnel with regard to doctrine, weapons and ammunition, shipboard organization, or shipboard operations. (See the official publications of these authorities on these matters.)

This is the first of three volumes on naval weapons. This volume (NavPers 10783) is concerned with all U.S. Navy weapons with the exception of guided missiles (and their control systems) and nuclear weapons. The second volume (NavPers 10784) is devoted to guided missiles and nuclear weapons, and the third (NavPers 10785, CONFIDENTIAL) is a supplement to volume 2. The titles of the second and third volumes are, respectively, Principles of Guided Missiles and Nuclear Weapons, and Navy Missile Systems.

This text is specifically designed to meet the needs of NROTC and OCS students. To cover the complex field with which it is concerned, the text concentrates on elementary functional operation of complete systems, rather than on descriptive details of a wide variety of individual instruments. The book is not written for maintenance or repair personnel. Ordnance Pamphlets and other technical publications issued by the Naval Ordnance Systems Command and the Naval Ship Systems Command are available for all equipments discussed in this book. They should be consulted for detailed information.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

CONTENTS

CHAPTER 1

INTRODUCTION TO NAVAL WEAPONS

Naval weapons have played and continue to play an important role in achieving battle victories, both on land and sea. In addition to their destructive power against ships and their gunfire support role, Navy weapons can be used to destroy enemy strongholds far inland.

NAVAL WEAPONS AND SEAPOWER

What is seapower? It is that portion of a nation's overall power which enables that nation to use the sea in furtherance of its interests, objectives, and policies. This definition implies two facets of control of the sea—control that permits the nation to use the sea as a highway open to itself and its allies, and control that permits the nation to prevent its use by the enemy.

Seapower depends directly on the armament of vessels (submersible and surface) and aircraft. The naval power that can most effectively bring its airborne and waterborne weapons to bear in a given area of the sea or air, controls that area in either or both of the senses mentioned in the preceding paragraph. The United States Navy's mission is to do its part in providing for the security of the United States and to support the national policy throughout the world. Its primary way of accomplishing this is to gain and maintain control of the seas, to use the seas for the nation's purposes and those of its allies, and, in time of war, to deny use of the seas to an enemy.

SOME BASIC TERMS DEFINED

Throughout this text you will encounter many unfamiliar terms. Most of these are defined in appendix I. Some of the basic terms are discussed here, however, to help you better understand the remaining chapters.

ORDNANCE, GUNNERY, AND BALLISTICS

This text is concerned with the study of naval ordnance and gunnery. Together, the terms ORDNANCE and GUNNERY embrace weapons and their use.

Ordnance comprises weapons and other physical equipment pertaining to them. All this is further classified as explosive ordnance (which includes gun ammunition, missiles, torpedoes, mines, bombs, and rockets) and inert ordnance, which includes projecting devices (such as guns, launchers, and release gear), protective armor, and all equipment needed to operate and control weapons. Aboard ship it refers to all elements that come under the general term "ship's armament."

Traditionally, gunnery is the art and science of using guns. Weaponry is concerned with the practical use of all ordnance.

BALLISTICS is the science of projectile motion. (In this book, unless otherwise qualified, the term ballistics refers to the motion of projectiles fired from guns.) It falls naturally into two aspects: interior ballistics, which relates to the motion of the projectile within the bore of the gun, and exterior ballistics, which considers the action of the projectile in flight.

Each of these fields is the subject of careful and detailed study by specialists. Their findings are of enormous importance in gun design and in the development of fire control instruments. A general understanding of ballistics is essential to the naval officer afloat, so that he may achieve the best results with his ordnance equipment.

NAVAL WEAPONS AND ASSOCIATED EQUIPMENT

The weapons to be discussed in this text include:

GUNS. Essentially a gun is a tube closed at one end, from which a projectile is ejected at a

high speed by gases produced by a burning propellant. Guns may be used against surface, shore, and air targets.

ROCKETS. The essential component of a rocket is a propellant-filled tube equipped with a nozzle at one end. The burning propellant produces gases which are ejected through the nozzle; the rocket is driven by the reaction thrust developed.

GUIDED MISSILES. A guided missile is any unmanned vehicle moving above the earth's surface whose path can be changed by a mechanism within the vehicle. A ballistic missile is a guided missile designed to follow for a substantial part of its flight a ballistic (free or unsteered) trajectory.

AHEAD THROWN WEAPONS. These are explosive antisubmarine weapons fired forward of the attacking surface vessel. They may be propelled by gunlike projectors or by rocket motors.

TORPEDOES. A torpedo is a self-propelled underwater explosive missile used against submarine and surface targets.

MINES. A mine is an underwater explosive weapon which in performing its function is not propelled, but is actuated when it is approached or touched by a target.

DEPTH CHARGES. A depth charge is an antisubmarine weapon dropped or fired from surface vessels and designed to function either at a preset depth or in proximity to a submarine.

BOMBS. A bomb is any missile, other than torpedoes, mines, and guided missiles, that is dropped from an aircraft.

NUCLEAR (ATOMIC) WEAPONS. Nuclear weapons are explosive devices which obtain their disrupting energies from reactions in and between atomic nuclei. In context, the term special weapons means nuclear weapons.

RESTRICTED WEAPONS. These weapons include atomic, biological, and chemical types. Special doctrines apply to the use of these, and they are kept under the tight direct control of the President.

This volume does not cover nuclear (atomic) weapons or guided missiles; for these, see the next two volumes in this series.

The methods and devices used to control guns and other weapons or weapon launchers constitute fire control. With guns, fire control can be considered as the practical application of exterior ballistics to ensure that the projectile will hit the target. With nonballistic weapons (such as surface-to-air guided missiles, torpedoes, and mines) fire control comprises the control of weapon launchers and weapons so that the weapons will function in the desired manner.

Some equipment included in weapon control systems are:

SIGHTS. Sights are optical devices which establish the line of sight to the target and provide for positioning the gun so that its projectile will hit the target.

RANGEFINDERS. Rangefinders are optical devices used to measure the distance (range) to the target.

RADAR. Radar uses echoes of high-frequency radio pulses to establish continuous values of target elevation and bearing (which corresponds to the line of sight to the target) and target range.

GUN DIRECTORS. Gun directors incorporate optical sighting and radar equipment (generally) which establishes the location of targets and controls the positioning of guns so that their projectile will strike the target. Gun directors may be located at some distance from the guns they control, or they may be quite close, depending on type and size, but they are usually higher in the ship's structure. Directors may or may not include computer equipment. Directors for torpedoes are associated with sonar equipment for underwater fire control. Some gun directors may be used to control rocket or missile launchers.

FIRE CONTROL COMPUTERS OR RANGEKEEPERS. These are electronic or electromechanical devices into which are fed the mathematical variables in the fire control problem, and which yield solutions in the form of control settings required for the weapon and launcher to have maximum effect on the target.

STABLE ELEMENTS OR STABLE VERTICALS. Stable elements or stable verticals are gyroscopic devices that maintain a reference horizontal, independent of ship's pitch and roll, for use in solving the fire control problem.

DATA TRANSMISSION SYSTEMS. Data transmission systems are electrical lines and devices used for transmitting, with optimum precision, electrical signals corresponding to fire control information from one equipment component to another.

SONAR. Sonar is the underwater analogy of radar. It functions by detecting echoes of pulses of ultrasonic sound, and furnishes range, bearing, and depth of targets.

WEAPON SYSTEMS. The naval officer today thinks of these weapons and associated equipment not as individual units but as weapon systems. NWP 10 series defines a weapon system as the combination of a weapon (or multiple of weapons) and the equipment used to bring the destructive power of the weapon against the enemy. It goes on to point out that maximum weapon capabilities are realized when associated units are conceived and developed by properly relating them to other elements in their operational environment.

The weapon system concept, which is not new, finds its most thoroughgoing application with newer weapons such as guided missiles. Although the formal recognition of the concept is relatively recent, its implications have been understood for some time, and for this reason it is possible to consider certain combinations of weapons with other equipment as constituting a "system" even if the combination is not formally designated as such. The concept is therefore applied in later chapters of this book when, for example, the student takes up common combinations of gun directors, other fire control equipment, and gun mounts.

ORGANIZATIONAL RESPONSIBILITY FOR ORDNANCE

Any military organization must make some provision for the procurement of weapons, for supplying them with ammunition, for supplying them to personnel or installing them on vessels, vehicles, or aircraft, for keeping them in working condition, etc. These responsibilities are allocated to an organizational unit called an "ordnance department" or the equivalent.

In the United States military system, from the point of view of the Navy, these responsibilities are assigned most importantly at three levels—in the Department of Defense (for the entire military establishment), in the Navy Department (for the fleet and for shore facilities), and in the individual ship's weapons department. (These responsibilities appear also at other organizational levels, but are not taken up in this book.)

ORDNANCE RESPONSIBILITIES IN THE DEPARTMENT OF DEFENSE

The Department of Defense was created as a part of a program designed to provide for the future security of the United States through the establishment of integrated policies and procedures for the agencies of the Government concerned with the national security. Figure 1-1 is a simplified chart of the Department of Defense, emphasizing the relationships described below.

16.1
Figure 1-1.—Organization of the Department of Defense.

At the head of the Department of Defense is the Secretary of Defense, whose staff includes a number of assistant secretaries and others. (The Secretaries of the Army, Navy, and Air Force have a line relationship to the Secretary of Defense.) So far as ordnance is concerned, the most important member of the Defense Secretary's staff is the Assistant Secretary of Defense (Applications Engineering). This Assistant Secretary is concerned with engineering phases of development, design, and production of weapons and weapon systems, particularly with respect to military and engineering standards and characteristics, economy in use and maintenance, and production scheduling. The Assistant Secretary (Logistics) and the Assistant to the Secretary (Atomic Energy) are also concerned with ordnance matters—respectively as regards supply and atomic weapons. (For details on

Defense Department organization, see the U.S. Government Organization Manual, issued annually by the General Services Administration.)

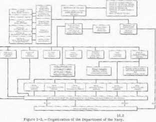
With respect to ordnance, as with other matters, the Navy functions as a member of a team which includes the Army and Air Force. Ordnance equipment is usually developed by and procured by the service primarily interested. However, there are hundreds of ordnance items used by all three services, or by at least two of them. For instance, the Navy and Air Force both use Army rifles and pistols; the Air Force carries Navy mines, and the Navy uses Air Force bombs; the Army uses some Navy projectile fuzes, and the Navy uses several Army rocket fuzes. When one service procures a device for another, it usually furnishes all appropriate spare parts, instructional materials, and special tools as well.

The Marine Corps and Coast Guard do not maintain ordnance departments. Except for a few specialized items of equipment, they are dependent for their ordnance on the Army, Navy, and Air Force.

NAVY DEPARTMENT RESPONSIBILITIES FOR ORDNANCE AND GUNNERY

Within the Navy Department, Naval Ordnance Systems Command (NavOrdSysCom or NavOrd) is chiefly responsible for ordnance material. Figure 1-2 shows NavOrd in the Department of the Navy organizational structure. As defined by Navy Regulations, 1948:

> "The Bureau of Naval Weapons (which is now NavOrd) shall be responsible for the following, except as otherwise prescribed in these regulations or by the Secretary of the Navy:
>
> "The design, development, procurement, manufacture, distribution, maintenance, repair, alteration, and material



16.2

Figure 1-2.—Organization of the Department of the Navy.

effectiveness of naval ordnance; the research therein; and all pertinent functions relating thereto, including the control of storage and terminal facilities for, and the storage and issue of, ammunition and ammunition details.''

Naval Ordnance Systems Command's responsibility includes ordnance material for ships and small craft, and that used by Marine troops. Naval Air Systems Command is responsible for aircraft ordnance.

The excerpt from Navy Regulations pertaining to the responsibilities of the Bureau of Naval Weapons is not entirely true for NavOrd. For example, weapons research and development comes directly under the control of the Chief of Naval Material.

The Naval Ordnance Systems Command has several field activities under its control. These activities include naval ammunition depots, naval ordnance system support activities, naval weapons stations, and naval ordnance laboratory test facilities.

The Chief of Naval Operations (CNO) controls, through fleet and force commanders, the operational use of weapons, with appropriate liaison with the technical commands concerned. The CNO also controls operational and team training in the use of weapons.

The Bureau of Naval Personnel (BuPers) is responsible for the training of officers and enlisted men (as individuals) in the use and maintenance of weapons.

The Naval Ship Systems Command (NavShips) is concerned with design problems in installation of ordnance in ships.

Naval Supply Systems Command (NavSup) is responsible for the general fiscal management of the Navy (except personnel matters), including those aspects that are concerned with ordnance.

Full details concerning the relationship of each Naval System Command with ordnance and gunnery are published in the manual that governs the organizations and operation of that command. The CNO Organization Manual performs the corresponding function for CNO.

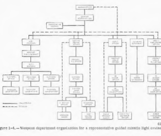
FUNCTION OF THE SHIPBOARD WEAPONS DEPARTMENT

Naval ships are organized into departments, which are further broken down into divisions. In ships-of-the-line—that is, those ships which have been designed primarily to launch or fire weapons—the ordnance department is called the weapons department. The weapons officer is the head of this department. He is responsible for all of the ship's armament, and its deck seamanship and related equipment. The weapons officer will have certain officer assistants within the department who direct their attention to specific weapons, equipment, and administrative matters. The duties of these weapons assistants are discussed in chapter 15. Notice in figures 1-3, 1-4, and 1-5 that the weapons departments consist of several divisions, each headed by an officer assistant who bears a title descriptive of his duties, e.g., Fire Control Officer, Missile Officer, etc. In figure 1-4 you can see that a division officer's job on a cruiser is a primary billet, but this same job may be a collateral duty on a destroyer, as shown in figures 1-3 and 1-5.

In ships whose offensive characteristics are not primarily related to ordnance or aircraft, deck responsibilities will overshadow weapons. In such cases (usually auxiliaries and support ships) the first lieutenant is assigned as head of the department and as assistant for weapons. The weapons (or gunnery) officer is the assistant head of department, and the department will probably be called the deck department.

The details for weapons department organization must be separately established for each type of ship. Although there is considerable variation from one ship type to another, certain

63.5
Figure 1-3.—Weapons department organization for USS Forrest Sherman Class DD.



63.3

Figure 1-4.—Weapons department organization for a representative guided missile light cruiser.

general aspects of organization apply to all ship types. There is a designated head of department (weapons officer, or first lieutenant) and he is assigned certain assistants. The number and titles of his assistants vary with the type of ship, its weapons installation, and the number of officers on board.

Further details on the organization and operation of the shipboard weapons department can be found in Navy Regulations, 1948; in Shipboard Procedures, NWP-50; and in directives from the Chief of Naval Operations and type commanders.

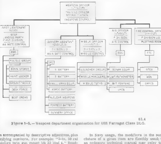
IDENTIFICATION OF ORDNANCE EQUIPMENT

Never underestimate the importance of cataloging, classification, and nomenclature when dealing with ordnance. In fact, the word "ordnance" is related to the word "order," in the sense of arrangement or classification. Its use in connection with weapons has been traced back to England's Henry VIII, in whose reign the royal armament was classified and cataloged.

Ordnance classification, cataloging, and standard nomenclature, which were a welcome innovation in the 16th century, became an unavoidable necessity in the 20th. In this text it will not be possible to describe in detail the complexities of U.S. naval ordnance cataloging and classification. This section will attempt only to explain enough to make the main principles clear.

NOMENCLATURE AND IDENTIFICATION

The standard nomenclature for any item of naval ordnance equipment includes a basic noun,



63.4

Figure 1-5. — Weapons department organization for USS Farragut Class DLG.

often accompanied by descriptive adjectives, plus identifying numbers. For example: "3-in. 50 cal rapid-fire twin gun mount Mk 33 Mod 4." Reading this from left to right, "3-in." specifies the bore diameter or caliber, "50-cal" specifies the gun barrel length in terms of calibers (since this is a 50-caliber gun, its length is 3x50 or 150 in.); "rapid-fire" indicates that its ammunition is fed into the gun automatically by a power-driven loader; "twin" indicates that the complete mount assembly incorporates two gun barrels mounted in parallel. The basic noun here is "mount," which here includes not only the gun barrels with their breech and recoil mechanisms, but also their training and elevating gear, gun mount shield, power drives, power rammer and loader, and fire control and sighting equipment located on the mount. "Mk 33 Mod 4" is abbreviated from "Mark 33 Modification 4," which specifies a particular version of a certain mount design.

In Navy usage, the modifiers in the nomenclature of a given item are flexibly used; thus, an ordnance technical manual may refer to the gun mount named above merely as "3-in. mount Mk 33 Mod 4." This represents the minimum. Note that the reference to "gun" is omitted. When not otherwise specified, a mount is always a gun mount.

The mark number identifies a major item (like a gun mount) or principal component (like a sight or a power drive) of a particular design. When the Navy makes a basic change in design, or designs new equipment of the same general type, the name remains the same but a new mark number replaces the old. Thus the Mk 33 Mod 4 twin mount mentioned above has a different mark number from the generally similar Mk 34 single mount, and also a different mark number from the Mk 27 twin mount, which differs significantly from the Mk 33 in the design of the slide. The mod number (mod here stands for modification

not model) indicates a minor design change or alteration. For example, the Mk 33 Mod 4 mount mentioned above differs from Mod 2 chiefly in that Mod 4 has an aluminum shield while Mod 2 has not. Modifications may be made also because of improvements in design based on experience, or to adapt the equipment for mounting in different places or for operation with different associated equipment.

The nomenclature of any naval gun barrel or mount always includes its caliber. There is a separate series of mark numbers for each caliber; for example, 3-inch and 5-inch gun barrels are numbered in different series. However, as long as the bore diameter is the same, gun barrels are numbered in the same series, regardless of bore length. Thus, both 5-inch gun barrels — the 5"/38, and the 5"/54 (and their mounts) — are numbered in a single series.

The mark and mod numbers, as well as the rest of the nomenclature, are assigned by the Naval Ordnance Systems Command. The place to find this official nomenclature is the current edition of Ordnance Pamphlet (OP) 0. (This publication is described later in this chapter.) For nomenclature of components or parts of units designated by mark and mod, use the OP or the ordnance supply catalog for the equipment concerned.

Gun mounts are identified not only by mark and mod but also by assembly number. This is so because gun mounts (especially the larger ones) are not single units, but are really combinations of smaller units, each of which has its own mark and mod. For instance, the 5-inch Mount Mk 39 Mod 0 may be equipped with any one of a number of different mods of the Elevation Indicator-Regulator Mk 54, or with one of several mods of the Train Indicator-Regulator Mk 46. It may have either Mod 0 or Mod 1 of the Mk 54 shield, and so on. Each assembly differs from the other in details like this. Each assembly is, therefore, designated by an assembly number to distinguish it from the others.

Each individual unit of a given mark and mod has its own serial number. Identification by mark and mod is standard usage for weapons and fire control equipment. Some types of fire control radar use mark and mod designations, but most fire control radars, sonars, and other electronic equipment use a different system which is fundamentally composed of two groups of letter prefixes followed by an identifying number. An example is "Sonar equipment AN/SQS-23." Letter group "AN" means that the nomenclature complies with the system adopted jointly by the U.S. armed forces. In the following group, "SQS," the first "S" identifies the type of installation (it stands here for "water surface craft,") the "Q" stands for the type of equipment (sonar and underwater sound), and the final "S" indicates the purpose (detecting and/or range bearing). The numeral "23" serves as a model number, or the equivalent of a mark number. (However, modification numbers are not used in this system. Instead, a letter suffix "A," "B," etc., follows the model number.)

A complex electronic equipment like a sonar or radar system usually consists of several interconnected units. A letter group prefix is used instead of "AN/" to identify such a unit. For example, "IP-SQS-23" might be used to designate a cathode-ray display indicator tube used in conjunction with the AN/SQS-23 system.

Navy ordnance equipment (such as small-arms weapons) and ammunition procured from the Army normally retain the Army model designation, which consists of the letter "M" (standing for model), followed by a number corresponding to mark number, then (if there are modifications) by the letter "A" followed by a number designating the mod. Thus "Carbine, cal .30, M3A1," identifies a certain carbine with a bore of 0.3 inch as what would correspond in Navy terminology to Mk 3 Mod 1.

Aircraft bombs which have been adopted jointly by the Air Force and Navy are identified by AN-followed by either Army style numbers (M__ A__) or Navy mark and mod numbers.

NAMEPLATES AND OTHER MEANS FOR IDENTIFYING EQUIPMENT

Each item of equipment assigned a mark and mod number or equivalent bears a metal nameplate secured to some easily visible spot on its exterior. This plate is engraved or otherwise marked to provide the following information:

Standard nomenclature of the equipment, including mark and mod or equivalent, and identification of the system of which it is a part (unless it is an individual self-contained item).

Standard Navy Stock Number, Federal Stock Number, or other catalog identification.

Name of cognizant Naval Material Command agency (i.e., the Navy agency that procured the unit).

Manufacturer's part number or drawing number.

Name of manufacturer.

Number of contract under which the equipment was supplied.

Serial number, assembly number, or other numbers which identify the specific unit. Items produced in large quantities may have a lot number instead of a specifically assigned serial or other number.

The nameplate will probably also contain other information, such as the voltage and frequency of electric power to be supplied to the unit, precautions to be observed in using it, and blanks for recording alterations that have been made to the equipment. But the information listed above is approximately what you can normally expect to find. There will be some minor differences in equipment procured by different agencies of the Navy, but the nameplate will always be the best primary source for identification of equipment. It is obvious that the nameplate must never be detached, defaced, obliterated, or permitted to become illegible, either through neglectful accumulation of grime and dirt, through being painted over, or through overdiligent scouring that erases the information it contains. Nor may the information on it be changed or added to, except as specifically directed by the cognizant technical command.

Many smaller assemblies and parts can be identified by numbers or coded markings. Numbers printed or engraved on parts or assemblies may be catalog numbers, Navy or contractor's drawing numbers, or code symbols that correspond to symbols on schematics. For most effective use of all of these, it is necessary to have available the technical manual or instruction book for the equipment, as well as (if possible) the appropriate part of the Navy's material catalog and available prints of the drawings on the equipment. With these, it is possible to establish positive identification of all parts and assemblies of the equipment.

The preceding paragraphs cover only the bare outline of the equipment identification and nomenclature systems used in the Navy. The subject is a complex one which can be completely mastered only by considerable specialized study.

In referring to a piece of ordnance, the information needed for identification depends upon the circumstances. For example, to identify the entire equipment as a functioning unit, the name, mark, and mod will be sufficient. But for requesting spare parts from the Ordnance Supply Office, the serial number (and the assembly number, if any) may be necessary in addition to the Federal Stock Number. These, together with mark and mod numbers, identify the specific unit involved, which enables the supply officer to contact the manufacturer if necessary.

FURTHER EDUCATION IN ORDNANCE AND GUNNERY

In your four-year NROTC program your chief opportunity for training in naval ordnance and gunnery (in addition to this text) up to the time you graduate will come during a summer cruise prior to graduation. At this time, you can expect a tour of training duty in the weapons department of a ship—quite likely aboard a destroyer or escort vessel, or possibly aboard a cruiser or carrier. This cruise will give you experience in working as part of the weapons department at several different points. You may have an opportunity to serve in a number of general-quarters stations—in ammunition handling in gun mounts, in gun laying and firing, in fire control directors, in fire control or missile plot, in sonar and underwater battery plot, and at torpedo and guided missile control stations. To make sure that you are successful in your later career on active duty, you will have to make the most of this shipboard training.

You will probably find that the subject matter of naval ordnance and gunnery is intrinsically interesting, particularly when you have the opportunity to work with the weapons and the equipment itself on board ship. But even if your primary area of interest is elsewhere, it is well to remember that all naval line officers have weapons department assignments sooner or later in their careers, and that it is worth working to make such assignments successful and profitable in terms of broadening your background and increasing your knowledge and experience. Moreover, your life and the lives of your shipmates may depend on your effectiveness as a member of the weapons department.

UNDERGRADUATE TRAINING IN RELATED SUBJECTS

This text on naval ordnance and gunnery is to some extent self-contained in that it includes in chapter 3 the principles of mechanics, hydraulics, electricity, electronics, optics, and sound as they apply later in the text. The basic material in this book and the mathematics and physics training that you have had are only a bare minimum. Amplification of this minimum

is strongly recommended. Valuable reading material that would solidify the basis on which your naval training will be founded would include texts on college chemistry, advanced mathematics (through calculus), elementary drafting, elementary electricity, electronics, nucleonics, mechanical engineering, and elementary aeronautical engineering (particularly with reference to guided missiles). All of these are not likely to be possible for all students, but any that you can study will be of great advantage. In planning your choice of technical study material, you would do well to consult with your Professor of Naval Science so that you can select material of maximum value in your naval career.

TRAINING ON ACTIVE DUTY

It is true that education does not end when you receive your diploma. It applies to your naval career as well as other aspects of your life, and it applies regardless of how you earned your commission.

When you are on active duty aboard ship, your professional education may be continued both on the job during duty hours and watches, and on your own time through personal study and through correspondence courses. This book by no means delimits the boundaries of your learning. The next section indicates possible study material sources that you should investigate once you are on board ship and in a position to take advantage of them. You can obtain details on correspondence courses through your education officer. Most of the books that you will find it profitable to study will be available aboard ship; the others can easily be obtained through routine channels. These study sources will help you both in training for current assignments and in preparation for future work of more scope and responsibility.

You will find special educational value in ship and fleet exercises and drills. You will get more out of such exercises if you prepare for them by studying the appropriate doctrinal publications in advance, and if you participate in the technical preparations your fellow officers and leading petty officers make for them.

OCS STUDENTS

During your intensive training period, you, as an Officer Candidate School (OCS) student, will be more or less limited to this textbook and other study materials on ordnance and gunnery that are furnished by the school. The suggestions in the preceding paragraphs on "Training on Active Duty" apply to you as an OCS graduate as much as they apply to all other naval officers—and you have probably learned by now that a conscientious naval officer's professional education continues all through his career.

PUBLISHED SOURCES OF INFORMATION

The competence of a naval officer depends not only on what he knows, but also on his ability to find quickly a reliable, authoritative source for other information he needs. For this he must depend on and be well acquainted with published sources of information.

The principal types of Navy publications which you as a naval officer aboard ship will use in connection with ordnance and gunnery include technical, tactical, and training publications.

TECHNICAL PUBLICATIONS

Most of the technical publications the weapons officer is concerned with are issued by NavOrd. Other technical publications are handled by NavSup. Naval Supply Systems Command operates Naval Publications Supply Center at Philadelphia, Pa. The available publications are indexed in NavSup Publication 2002, Cognizance Symbol 1.

Ordnance Pamphlets (OPs) are of two types. Most OPs are of the type that serves as a technical manual on a specific ordnance equipment, including a description of the equipment, its operation, maintenance, installation, and repair. The other type of OP, of which there are relatively few, is a treatise on some ordnance subject such as battery alignment or ammunition. All OPs are indexed in OP 0. They are numbered consecutively without any attempt at coding.

Ordnance Data (OD) publications are used for publishing a variety of technical information, including test and inspection information, advance information or instructions on ordnance equipment, and ordnance equipment lists for specific types of ships. ODs are numbered serially and are indexed in OP 0.

Ordnance Alterations (OrdAlts) prescribe specific authorized changes (as distinguished from repair and other maintenance work that does not alter the design or characteristics of the equipment) in specific ordnance equipment. Alterations of ordnance equipment are permitted only as authorized by OrdAlts, and they must be made strictly in accordance with the drawings and

instructions that form part of the OrdAlts. After they are completed, they must be recorded in the maintenance records of the weapons department and reported to NavOrd. OrdAlts are listed in a special index published as OrdAlt 00.

Ordnance Instructions and Ordnance Notices are NavOrd-issued directives published in accordance with a decimal numbering scheme prescribed by the Office of the Secretary of the Navy. This scheme provides for subject classification and numbering of issues relating to administration, supply, procurement, production, fiscal matters, and the like. NavOrd directives are indexed in NavOrd Note 5215.

The ordnance section of the Coordinated Shipboard Allowance List (COSAL) is the authority for issue of ordnance material to ships. COSAL includes the spare part items for all departments on the ship. The COSAL does not include resale clothing, bulk fuel, medical supplies, recreational equipment, and expendable ordnance. These items (as well as some others) are covered by separate outfitting and load lists. Each COSAL is tailored to meet the needs of a specific ship, and it is prepared in segments by category of material in simplified and uniform format. (A more detailed discussion of the COSAL may be found in other NavPers publications, including Military Requirements for Petty Officer 3 & 2, NavPers 10056-C.)

NavOrd Bulletins are classified, quarterly periodicals containing articles on new developments in naval ordnance, equipment in the fleet or under development, new safety information, newly developed modifications to ordnance gear, and other timely information. They also list new publications issued since the latest issue of OP 0.

Weapons department personnel use and may maintain a considerable amount of equipment under the cognizance of NavShips — equipment such as dredger hoists, compass repeaters, sonar gear, speed indicators, and wind data receivers. Technical manuals for such equipment are published by NavShips and furnished to weapons department personnel.

Weapons department personnel also maintain all or part of such systems as high-pressure air distribution systems and sprinkler systems. For technical information on these systems, see the appropriate drawings (ship's plans), your ship's Damage Control Book and General Information Book, and the NavShips Technical Manual. The NavShips manual consists of a number of separate chapters, each bound like an independent pamphlet, and each on some aspect of the ship's structure or plant.

TACTICAL PUBLICATIONS

The Chief of Naval Operations (CNO) issues several series of publications intended to present doctrines and procedures for the use of U.S. Navy ships, aircraft, and weapons in combat. In naval warfare usage, a doctrine may be defined as a working principle or rule of combat that has been developed theoretically and proved by experience. Procedures are methods used to put the doctrine into effect. These publications are concerned also with team combat training — the training of groups in fighting units, as distinct from individual training mentioned later on in this chapter. All these doctrinal publications are classified.

The primary series of doctrinal publications issued by the CNO are Naval Warfare Publications (NWPs). There are four groups of these. Group I takes up basic principles and planning, groups II and III are devoted respectively to naval operations and the procedures they require, and group IV deals with specific fleet exercises. The group I doctrinal publications also include, besides NWPs, several Allied Tactical Publications (ATPs) and Allied Communications Publications (ACPs); these apply in the U.S. Fleet as designated by the CNO. The group IV publications are identified either as Fleet Exercise Publications (FXPs) or Allied Exercise Publications (AXPs), not as NWPs.

Supplementing the primary doctrinal publications mentioned above are the Naval Warfare Information Publications (NWIPs) and several ATPs and FXPs. These expand in detail certain aspects of primary publication content. The entire doctrinal publications system is described in NWP 0, which contains charts explaining in detail the interrelationships among the publications mentioned above, and has detailed indexes of their contents.

In your duties aboard ship as an officer in the weapons department, you will find that the doctrinal publications most useful to you at the outset will be:

1. The publications directly concerned with the type of ship you are on, its mission, and often your assignment in your department. For example, if the DD you are in is preparing for amphibious operations and you are assigned as weapons liaison officer in CIC, you should be studying NWP 22, NWIPs 22-2 and 22-7, NWP 31A, ATP 4,

and appropriate parts of FXP 3. These have to do with amphibious operations, CIC operations, naval gunfire support, and fleet exercises (including amphibious).

2. ATP 1, Volume I. The information here is essential to any officer assigned as watch officer, JOOD, or OOD, particularly when underway.

3. NWP 10, a basic publication on the principles of sea power and the U.S. Navy's mission. In some commands this is more than recommended reading; it is required.

4. NWP 50. The student should concentrate on those parts of this book that deal with weapons department organization and operation, and the relationship of the weapons department to other shipboard departments.

TRAINING PUBLICATIONS

The Bureau of Naval Personnel (BuPers) is charged with all training of naval personnel other than group combat training (which is under CNO). BuPers therefore issues all text material specifically designed for training purposes and intended for Navy-wide distribution. The book you are now studying is a BuPers publication of this type. The training materials published by BuPers fall into the following categories:

1. Navy training courses for enlisted personnel. Most of these are intended for enlisted personnel to study in preparation for advancement to specific ratings and grades, but some are courses in common subjects such as electricity and mathematics.

2. Navy courses for officer personnel. These cover subjects of specific interest to officers, such as this book and The Weapons Officer, NavPers 10857 series.

3. Correspondence courses on specific subjects. These are designated as enlisted or officer courses. The courses are based respectively on the texts of the two types mentioned above. Officer courses are available to personnel on active duty or in the reserves. They are administered by the U.S. Naval Correspondence Center, Scotia, New York.

4. Special-purpose publications that do not fall into the categories above, such as the periodically issued List of Training Manuals and Correspondence Courses, NavPers 10061 (followed by a letter indicating the revision). NavPers 10061 serves as a catalog of NavPers publications.

Aboard ship, the officer newly assigned to the weapons department will probably find most useful a copy of the books in the present series, plus The Weapons Officer, NavPers 10857, and such others as will be applicable to his assigned duties. NavPers 10061 is a good reference to investigate for this purpose.

SAFETY PRECAUTIONS

A universal objective of all U.S. naval training programs for all personnel is safety education. Active attention to safety is a part of all courses taught in Navy schools, and all training publications are concerned with it as well as with their principal subject matter. All supervisory personnel, enlisted and commissioned, are concerned with safety.

Since safety is so all-pervading a subject, it is obviously impractical to try to divorce it entirely, for study purposes, from the activities and operations with which it is connected. To indicate the type of safety considerations that the Navy deems important in connection with ordnance, an extract from the Navy publication U.S. Navy Safety Precautions is reprinted as an appendix to this book. However, the weapons department officer aboard ship should be aware of other primary sources of information on safety available to weapons department personnel. They are listed here for reference purposes.

1. Technical publications issued by NavShips and NavOrd on equipment under their cognizance contain safety information as required in connection with proper operation, maintenance, and adjustment of the equipment.

2. NavOrd also issues OPs on certain aspects of safety, as follows:

a. OP 4, Ammunition Afloat, and OP 5, Ammunition Ashore, Handling, Stowing, and Shipping.

b. OP 1014, Ordnance Safety Precautions; Their Origin and Necessity.

c. OP 1591, Clearing of Live Ammunition From Guns.

3. BuPers issues the following publications containing safety information:

a. The Weapons Officer, NavPers 10867.

b. Navy training courses (including basic courses) contain safety information in appropriate contexts.

4. Other sources.

a. Safety placards and cautionary nameplates appear on equipment and in its vicinity where considered advisable for the warning of operating and maintenance personnel.

b. Army technical publications, used in the Navy particularly for small arms, have considerable safety information as it concerns small arms and ammunition.

CHAPTER 2

SHIPBOARD WEAPONS AND WEAPON SYSTEMS

Shipboard weapon systems—crude as they may have been—have existed for many years. The older systems were less complex (and less accurate) than the ones today, but they were weapon systems nonetheless.

A weapon system is, according to the definition given in NWP 10, the combination of a weapon (or multiple of weapons) and the equipment used to bring the destructive power of the weapon against the enemy. Before guns were invented, the ship was used to sink or damage an enemy ship by ramming it. This tactic was used occasionally as late as World War II.

In this chapter, we are concerned with the weapon systems (e.g., gun, missile, and torpedo) within the ship and not with the ship itself as a weapon system. Also, we will briefly discuss weapons and their revolution, detecting devices, weapon delivery devices, and weapon control units.

EVOLUTION OF NAVAL WEAPONS

In your naval orientation course you studied the influence of seapower on world history, tracing it as far back as the wars in ancient times between the Greeks and the Persians. You may recall how Roman seapower turned the Mediterranean into what the Romans called "Mare Nostrum" (our sea), so that the invading Carthaginians had to go hundreds of miles overland to bypass Roman seapower. You may also recall how, following Columbus' voyages, seapower made Spain's access to the New World the root of her imperial power and how Britain later gained this power with a single major victory at sea. Examples of the influence of seapower on history could be multiplied. Instead, consider briefly now how evolving armament and the technique of using it have affected seapower in the past, and a few dominant trends in the future.

GUNS AND OTHER WEAPONS EFFECTIVE AT A DISTANCE

Warships in classical and early medieval times engaged each other effectively by ramming or by grappling and boarding for hand-to-hand combat. Until the development of the naval gun, this remained the classical pattern, although crossbows, incendiary pyrotechnics ("Greek fire"), and shipborne spring- or torsion-powered artillery did allow some battle action before actual ship-to-ship contact. As guns developed, ranges increased from 50 to 300 feet for early naval cannon to 40,000 yards and beyond for the World War II battleship. Most of this increase took place shortly before and during World War II. In our Civil War a mile was rather far for accurate gunnery, and even in the Russo-Japanese War (1905) the opening range was only about 6,000 yards. Aircraft and guided missiles have even more radically increased battle ranges.

The most significant results of the increasing range of seaborne weapons have been (a) an increase in the importance of naval firepower in land warfare, (b) an increase in its potency as compared to landbased firepower, and (c) an increase in the importance of amphibious warfare. Modern naval gunfire and aircraft can range many miles inland to attack specific objectives, to support land forces (as supplements to land artillery), and to support amphibious landings. Compare, for example, the successful Inchon beachhead (Korean War) with the Gallipoli fiasco (World War I).

The increase in range has increased the distance between combatant forces in purely naval engagements also, and it has had a number of other side effects. The extreme in this trend toward increasing separation between attacker and target has recently been attained by missiles which can span whole oceans to reach their targets.

The development of nuclear fission and fusion revolutionized not only weapons but also even the art of war, to say nothing of its effects (still not entirely known) on mankind in general. But explosives have been revolutionized before—first with the discovery of gunpowder, then with the invention of guncotton and its nitro-based successors, followed by the development of powerful but insensitive explosives, and the continuing improvements in gun propellants and in the later chemical explosives.

One effect of the increased lethal range of explosive weapons resulting from the use of the new explosives, particularly nuclear, has been an increase in the dispersion required to minimize combat damage to ships in convoy and combat groups. Coupled with the improvement of aircraft, undersea craft, and missiles, another effect has been to force the development of picket vessels and early-warning systems.

FUZES AND RELATED DEVICES

Projectiles designed to explode on impact were used soon after cannon were developed. They were quite unreliable and unsafe however. They were the "bombs bursting (prematurely) in air" that Francis Scott Key saw; they did relatively little damage, and did not become really practical until around the middle of the 19th century when adequate fuzes were first developed. Fuzes have since become more and more subtle and refined, from simple impact types through mechanical time fuzes and modern proximity fuzes. These last, in a general sense, include not only projectile fuzes that operate by radio transmission, but also the equally sophisticated underwater weapon devices—acoustic, magnetic, and pressure-sensitive—which are used in mines, torpedoes, and depth charges.

The result of all these developments has been an increase in the destructive efficiency of the weapons and projectiles in which they are used, in that the weapon or projectile will function effectively without actual physical contact with the target. The consequent increase in antiaircraft weapon effectiveness has to some degree offset the development of higher performance aircraft. Underwater, the effect has been to increase the complexities of defense and attack, as well as the dangers of both surface and undersea targets. Probably the most spectacular corollary of the development of sensitive underwater devices has been the concurrent development of the torpedo that can seek out and home in on its target. This, along with the snorkel, nuclear power, and hydrodynamic developments (e.g., the shape of the Albacore shown in figure 2-1) has had a revolutionary influence in changing submarine and antisubmarine warfare from what it was early in World War II.

UNDERWATER WEAPONS

Underwater weapons include the mine, the torpedo, and the depth charge.

The mine is a weapon effective at a distance, in time as well as space. After the mine is planted, it lies dormant until a ship (or other metallic object) comes close enough to detonate it. Mines are a means of controlling the sea by denying ships passage through it or making such passage extremely hazardous. An example of the effectiveness of mines in such an application during the Korean War was the enemy's mining of the Wonsan area, a relatively favorable landing site. This prevented the United Nations forces from making a second beachhead there, and impaired the effectiveness of the campaign to repel the North Korean-Red Chinese forces.

The automotive (self-propelled) torpedo, an unmanned explosive-laden submarine, was first developed in practical form in the 1870s. Early in the 20th century it was considered so potent (particularly in the days of metal ships lacking modern compartmentation) that special torpedo-boats were used to launch them. A specialized craft to counter the torpedo-boat was developed—the torpedo-boat destroyer, which has evolved into the modern DD. The torpedo (and torpedo-like weapon) is now the most advanced weapon used against submarines as well as the chief weapon used by submarines other than FBM.

Unlike mines and torpedoes, which can be used against either surface or submarine targets, the surface-launched depth charge (when dropped from aircraft, called the depth bomb) is specifically an antisubmarine device. When first developed in World War I, and until the midst of World War II, large depth charges were either dropped astern or heaved a few score yards over the side by a small propelling charge in a special gun, after which they were detonated by a hydrostatic device upon reaching a set depth. Currently used designs are much smaller. They

71.1-569
Figure 2-1.—U.S.S. Albacore (AGSS 569).

may be propelled by a rocket or a mortar device and are either contact- or proximity-fuzed, but their most important characteristic is that they can be fired at much greater ranges (up to several hundred yards). This has led to a change in antisubmarine warfare (ASW) tactics. ASW vessels are no longer forced to stay close to the target submarine, crossing and recrossing its presumed location which frequently caused the DD to lose sonar contact in its own screw noises. Weapons can be thrown ahead of the DD's track (ahead thrown weapons) to eliminate this difficulty. Newer depth charge weapons that extend the aerial flight time are discussed in a later chapter.

FIRE CONTROL

The improvements in gun ranges mentioned earlier could make guns effective only if the guns were adequately directed so that their projectiles would hit the target. The evolution of gun fire control as we know it today began in the 19th century with the invention of fixed sights, and continued with the development of movable sights (something like those on modern military rifles) in the 1840's, telescopic sights and drift- and windage-compensating sights (1850's and 1860's), fire control directors and optical rangefinders (World War I), analog fire control computers and plotting techniques (after World War I), and high-speed, digital fire control computers and automatic target acquisition and tracking (after World War II).

The most spectacular World War II fire control innovation was radar, which made accurate fire control possible even when optical instruments were useless. Radar has been mainly responsible for the enormous accent on the electronics characteristic of the fleet today. A prewar DD had, for example, perhaps 100 electron tubes altogether; a postwar DD has more than 3,000 tubes and transistors.

Parallel with the development of radar came the development of sonar. Even as early as World War I, hydrophones were used both by destroyers and submarines to listen for underwater and surface targets. The development of active ("ping") sonar revolutionized underwater detection by making possible the detection of passive targets (i.e., those that do not radiate noise). Although sonar and radar are similar in principle, their range and accuracy are not on the same order. (Radar has the advantage over sonar in both range and accuracy.) With the increased emphasis placed on antisubmarine warfare in recent years, sonar is being constantly improved. Modern sonar is capable of detecting targets at far greater ranges and depths than sonar of the World War II era. Sonar is invaluable in both surface and subsurface naval vessels.

CONCLUSION TO HISTORICAL DISCUSSION

The preceding paragraphs have indicated in broad outline some of the effects of developments in important naval weapons, but much has been omitted (guided missiles and rockets for example); and the development of the vehicles themselves (surface ships, submarines, aircraft, propulsion and navigation equipment, etc.) has not been covered. Some of the present trends in weaponry are indicated later in this chapter.

THE WEAPON SYSTEM CONCEPT

The effective use of any naval weapon requires that a payload (generally an explosive device) be delivered to (usually) a moving target. Accuracy in determining the location and velocity of the target is vital to the success of the attack. The result of the increase in target velocity and range has been that today, for effective use, a weapon must be considered and employed not individually but as part of an accurate weapon system.

ELEMENTS OF A WEAPON SYSTEM

The phrase "weapon system" was defined in general terms in the preceding section. We can now be more specific. A weapon system, taken as a whole, must include:

1. Elements which detect, locate, and identify the target.

2. Elements which deliver or initiate delivery of the destructive device of the weapon to the target. (The term "weapon" is used flexibly in different contexts; for example, a gun is a weapon which delivers a projectile to the target, while a mine is a weapon that itself explodes when a target activates it.)

3. Elements that control a delivery unit or weapon to direct its delivery; that set the fuze (or equivalent) of the destructive device; or (as with a torpedo) that "program" or preset a target-seeking device as required for maximum effectiveness in reaching the target.

4. Destructive payloads (usually termed "weapons") that will destroy the target when in contact with it or when in its vicinity.

Each of these types of component elements will be discussed in somewhat more detail later.

WEAPON SYSTEM REQUIREMENTS AND EVALUATION

The Navy has a rather elaborate series of stages through which any weapon or associated item must go from the time it is proposed until the solid hardware itself is installed for service use aboard ship. Although the fundamental idea on which the item is based may originate almost anywhere (ideas are welcome regardless of the source), it is the Chief of Naval Operations, speaking for the ultimate user, the fleet, who sets the requirements that the weapon or whatever it is must meet. The prototype (first installed model) of any instrument or piece of equipment which bears a Navy nameplate that you see on a naval vessel has been through exhaustive engineering and shipboard application tests, and meets the fleet's requirements for what that specific item must do, and how well it must do it.

The trend in recent times has been increasingly toward design and procurement of complete weapon systems, rather than of component units which later evolve into a system. This is especially true of newer systems such as missiles with their complex guidance and propulsion systems, as contrasted with most systems based on guns, which were not originally conceived as systems but evolved that way.

The statement of requirements for any weapon system or component unit can be considered as responses to two questions—

1. What is the system or component unit supposed to do?

2. How well is the system or component unit supposed to do it?

The answer to the "what" question is often called the "military requirements." It is a statement of the nature of the equipment (whether it's a gun, a torpedo, a radar, a computer, etc.) and its capabilities or what it can do (if a gun, its range, rate of fire, etc.; if a torpedo, its speed, range, accuracy, etc.; if a radar, its range, accuracy, sensitivity, etc.; if a computer, its speed, accuracy of solution, limits of operation, etc.). Obviously, all this is entirely dependent on the nature of the system or component

unit. Moreover, in a system, each component's requirements depend on the characteristics of the other components and on the requirements of the system as a whole. Thus, the capabilities of any system are limited by those of the "weakest link" in the system. (For example, a computer in an ASW system can solve fire control problems beyond the ranges possible to the sonar equipment in the system; the sonar's range therefore establishes the system's range.)

Aside from what we have here called the military requirements that depend on the nature and task assigned to weapon systems and weapon system components, there are some requirements that are generally applicable to all, regardless of the nature of the system or component. These can be considered as the answer to No. 2 above. We can state them here only in qualitative terms, since this is a general discussion; in system specifications those requirements are reduced to specific values:

1. RELIABILITY. The system must be capable of continuous long-period functioning under specified adverse conditions at specific rates (e.g., rounds per minute fired, or hits maintained at specified accuracy, etc.).

2. FLEXIBILITY. The system must be capable of functioning satisfactorily in spite of failures in quality of power supply, ammunition, etc.; it may also be required to function satisfactorily with certain components omitted or disabled, or with others substituted.

3. SAFETY. The system must be perhaps not foolproof, but hazardous conditions must be eliminated by interlocks or other means; it must not endanger friendly ships and aircraft or ownship structure or personnel.

4. SIMPLICITY OF OPERATION. Complex modern weapon systems cannot be made inherently simple, but they should be designed for facility of operation by human beings. These considerations influence design of control arrangements, provisions for safety and comfort of operating personnel, and functional design to make the equipment as simple to operate as its nature will permit.

5. MAINTAINABILITY. This requires not only design using long-life components, but also convenient (and in many cases almost entirely automatic) testing and trouble-diagnosing gear that is either part of or is easily connected to the equipment. Moreover, this requirement has led to the development of the unit replacement principle—thus, if an amplifier, for example, burns out, the procedure is not to test each component in it and make repairs as necessary, but to pull out the whole amplifier (which is a complete plug-in unit) and plug in a replacement. The defective unit can then be repaired later and put back in stock as a spare.

Note that in weapon component or system design these requirements often conflict with each other. For example, a fuzing system may be made so safe that it won't function reliably. Much of the work in weapon design is concerned with attaining practical compromises between conflicting requirements.

The evaluation of a weapon system or component unit can be defined as the study of the system or unit, measurement of its effects, and appraisal of its effectiveness. As in development of ordnance material, the trend is toward evaluation of complete systems rather than independent units; in system testing and evaluation, however, component units are tested individually as well as with relation to their systems. Before a system or component is accepted for fleet use, it must go through both TECHNICAL (i.e., engineering) and TACTICAL evaluation, following standard prescribed procedures.

COORDINATION AND DISPERSION IN WEAPON SYSTEM EMPLOYMENT

Concurrently with the increasing complexity of weapons and weapon systems, naval operations have become more complex. The variety and the effective ranges of weapons are increasing, and the speed and maneuverability of targets are increasing.

As the ranges and explosive effect areas of modern weapons have increased, they have dictated increased dispersion of formations of naval ships. Convoys and task groups arranged according to present day doctrine have ships much more widely spaced than was the practice before and during World War II. An attributable factor is the development of atomic weapons, which add to the blast and fragmentation effects of former conventional weapons (but, of course, on a much magnified scale) the threat of radioactive contamination. Another factor which makes wider dispersion necessary is the increased speeds of aircraft and missiles which may attack the formation. More dispersion is needed, in the direction of the threat, so that outer perimeter units may give early warning of an attack.

The effects of this dispersion requirement are to increase the difficulties of coordination and to increase the requirement for improved long-range underwater target detection performance.

DETECTING DEVICES

The first steps in the functioning of a weapon system are the detection, location, and identification of the target. Ideally, the device performing those functions should detect the target at maximum range, and establish the target's location, orientation, and velocity with respect to own ship, with maximum accuracy and minimum delay. At the same time this device should identify the target as to exactly what it is and whether it is enemy or friendly. Ideally, the device should be equally efficient regardless of which medium it operates in, regardless of the conditions in that medium, and regardless of interference originating with the enemy, with friendly forces, or with natural causes.

No detecting (for the present let this term include locating and identifying) device or system yet developed measures up, without possibility of improvement, to any of those ideals. The ideals are useful chiefly as standards by which the effectiveness of detecting devices can be judged. The principal detecting devices now used in the fleet include:

1. Optical devices.
2. Radar.
3. ECM (electronic countermeasures).
4. Sonar.
5. MAD (magnetic anomaly detection).

All except the last of these depend on detection of radiation—the first three on electromagnetic radiation, the fourth on sound radiation. MAD depends on detecting differences in magnetic fields.

Optical devices are invariably passive, i.e., they detect radiation emitted or reflected by the target, but don't produce the radiation they detect.

ECM equipment falls into the passive category when used for detection. But ECM gear also has an active mode for use in jamming the enemy's electronic detection equipment. Sonar may be either passive or active when detecting subsurface targets. Its active device produces radiation which it detects as a reflection from the target. In order for passive sonar to detect a target, it has to receive noise from the target. Radar can only be active.

OPTICAL DEVICES

Optical devices in weapon systems function to establish target bearing and (for air targets) target elevation. Some optical devices can measure the range to the target. Except for highly unusual atmospheric conditions, in which light rays reflected from the target to own ship are perceptibly bent by refraction, the line of sight (a straight line from target to observer) is truly straight. Optical devices which incorporate lens systems are designed to magnify the image of the target; this extends the capabilities of the human eye in target detection and identification.

Since optical devices depend on visible light reflected from the target, they are handicapped by darkness (unless the target is luminous), fog, and visible obstacles. Optical devices are always passive (i.e., they never provide the light that makes the target visible), but an attacking ship can illuminate a target by firing gun projectiles which release parachute-supported flares in the vicinity of the target, or by using aircraft to drop such flares.

At the present time, only a few U.S. Navy ships have night observation devices, but eventually, most Navy ships will have these. Night observation devices actually intensify the brightness of an image and are used for observation, surveillance, and for the aiming of weapons during night operations. They use natural light radiations of a very low level to produce a useful, visible image.

Since light, in general travels in straight lines, a target cannot be optically detected if it is entirely below the horizon (like target 2 in figure 2-2).

110.1

Figure 2-2.—Limits of optical detection.

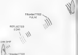
RADAR

In our short discussion of radar we will concentrate on its ability to measure the range or distance to a target. Navy radars can measure the target's angle of elevation above the surface horizontal, its altitude, and its true or relative bearing. This is, of course, if they are designed to do so. The target's speed can also be quickly determined if we add some minor computing units. In chapter 6 you will learn more about how radar works, but for now let's find out how it measures range.

Every naval ship is equipped with a powerful sound producer—its whistle. Suppose that the whistle on your own ship sounds a short, sharp blast while it is a mile or two distant from another ship. If you listen carefully after the blast sounds, you will hear an echo reflected from the other ship. If you know the speed of sound, and can measure accurately with a stopwatch the time elapsed between the whistle blast and the echo, you can easily determine the range to the other ship. This is a simple application of the distance, rate, and time equation which you learned years ago. You'll notice one slight variation however: the product of rate and time must be divided in half to account for the two-way travel of the sound wave.

If instead of a sound producer you use a powerful radio transmitter, and instead of your ears you use a radio receiver, you have the essentials of radar. (The name "radar" is an acronym for RAdio Detection And Ranging.) Figure 2-3 shows one transmitted pulse and one reflected echo as they travel between our own ship and the target. Notice that the transmitted pulse covers a larger area in space as it gets farther away from own ship. The amount of this increase depends on many variables, one of which is the type of transmitting antenna used. Notice also that the reflected echo is smaller in amplitude since only a portion of the transmitted energy is reflected by the target. Further, the echo expands as it approaches own ship and only a portion is actually received by the receiver.

To be of any use the reflected echo must be greatly amplified in the radar receiver before it can be displayed on the cathode-ray tube. The cathode-ray tube (similar to a TV picture tube) provides a visible display which can indicate target range, bearing, or elevation. The display in figure 2-4 is designed to provide range information only, and it could be the results of the situation in figure 2-3. The vertical "pip" or "blip" at the left of the sweep trace in figure

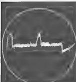


110.2
Figure 2-3.—Principle of radar.

2-4 represents the transmitted pulse; the center pip is the target echo. The sawtooth like shape at the right of the display is the range measuring device, which is called the "range step" in this case. You will see in a moment how the range step is moved to the echo to measure range, but, first, let's learn a little more about the sweep trace.

Even though the display appears to be continuously illuminated, it is in fact caused by a pencil-point beam of electrons which are made to "sweep" across the face of the scope from left to right. The sweep frequency is the same as the pulse repetition frequency of the radar. In layman language this simply means that every time a transmitted pulse leaves the antenna, a sweep is started. Actually, the sweep starts just a little earlier so the transmitted pulse can be viewed. The apparently continuous picture is the result of a property of the scope face called persistency, which means that a given point on the scope face continues to give off light for a short time after the beam of electrons has passed it. You have seen this effect before when you turned off a TV set and watched the illumination slowly fade.

The transmitted pulse, echo, and range step are traced by bending the beam of electrons above and below the vertical center of the scope, which is the normal vertical position of the sweep trace. Vertical deflecting plates or vertical deflecting coils are used for this purpose. In our example, the transmitted pulse must have been


110.3
Figure 2-4.—A common type of radar display.

applied to the vertical deflecting plates before the reflected echo, and the echo was applied before the range step. This is how the stopwatch is replaced. The designers simply arrange the scope so that a given portion of the sweep trace equals a certain number of yards (in some cases, miles). Then we can measure the trace distance, which is based on time, between the transmitted pulse and the echo. The sweep is made to move from left to right on the scope by horizontal deflecting plates or coils. The sweep movement is linear. It is based on time, and it is accurately matched to the range measuring circuitry.

In the preceding paragraph we mentioned "based on time"; let's explore this a bit further. The speed at which radar energy travels is 186,000 miles per second or 300,000,000 meters per second—the speed of light. Because of this great speed, the time elapsed between transmitting and then receiving an echo is measured in microseconds (millionths of a second, or µsecs). Obviously, a stopwatch will not do the job. As you have seen, a cathode-ray tube is used instead. With the speed of light as the reference, we find that radar energy travels 328 yards in 1 µsec. From this we can say that 1 nautical mile (about 2,000 yards) will be traversed by the energy in 6.1 µsecs. This is the time standard upon which most radars, and certainly most fire control radars, have been designed. Once again, it takes 6.1 µsecs for the energy to travel approximately 2,000 yards. These 6.1 µsecs represent 1,000 yards of RADAR RANGE.

Now let's measure the range to the target. A range counter is attached by mechanical linkage to a range handcrank, or to a range drive motor which drives the mechanical linkage. Moving the mechanical linkage by either method moves the counter and positions the range step to the corresponding position on the sweep. All the operator has to do to measure range is position the range step under the target echo and read the range from the counter. Moving the range linkage changes the time relationship between the transmitted pulse and the range step, and therefore controls the horizontal position of the range step on the sweep. If the range step were under the transmitted pulse, the range counter would read approximately zero yards. It would increase as the range step moves from left to right across the sweep in response to the operator's input.

Radar transmission is made from a metal structure called an antenna. Unlike the sound from a ship's whistle, which radiates almost equally in all directions, most of the energy in a radar pulse is directed along the bearing on which the antenna is pointed at the instant of transmission. The same antenna also picks up the echo. To get 360° coverage, radar antennas rotate continuously; antennas on radars designed to concentrate on a narrow angular sector are instead aimed by an operator. In addition, many of the latter type also oscillate or nutate through a small angle.

Radar signals are conducted to and from the antenna by special tubular waveguides that look something like ordinary air or water piping. Some use coaxial cables.

Radar shares many of the characteristics of optical detecting devices. Except for certain atmospheric conditions which to a minor extent distort the paths of the transmitted and reflected pulses, they travel in straight lines. As compared with a sound-ranging system like the one mentioned briefly by way of example at the beginning of this article, radar has much more range, functions several thousand times more quickly and much more accurately, and is not affected by audible noise. It is quite accurate (to within a degree) in measuring target bearing and elevation (though not quite as accurate as

optical devices). It is the most accurate and the longest in range of our range-measurement devices. It is not severely affected by adverse weather and fog, is just as usable at night as in the daytime, and is virtually immune to static and electromagnetic disturbances that plague communications radio and TV. Also, its signals can be used to guide missiles or to guide target-tracking equipment.

But radar has disadvantages too. It can be jammed or interfered with by enemy radar transmissions and other countermeasures. It does not permit easy identification by target silhouette or other visible characteristics; it shows only a blip for a target, and may show but one blip for several targets. As compared with optical methods, it requires skills in interpretation of its displays amounting almost to an art. Its complex electronic circuitry, waveguide plumbing, and mechanical rotating and nutating gear require constant attention to maintenance. As is true of any revolutionary technical advance that is depended on heavily, its loss through malfunction or battle damage is an especially severe handicap. Lastly, radar pulses can be detected by the enemy at much greater ranges than those at which the pulses will reveal to the originating ship the enemy's presence. As the discussion later of ECM will indicate, radar pulses are a telltale that may reveal a great deal of other information to the enemy also.

In spite of these disadvantages, radar is the primary means of detection used in the fleet today.

ECM

ECM (Electronic Countermeasures) have been defined as the means by which your own forces attempt to nullify advantages of enemy electronic devices, and to obtain all possible information concerning enemy electromagnetic radiations. ECM may be either passive or active.

Passive ECM are measures not detectable by the enemy. The most important is intercept search, by sensitive receiving equipment, of all electromagnetic wavelengths that the enemy might use, detection of electromagnetic radiations, and determination of their source and characteristics. Intercept search will detect radiation from any kind of electronic equipment — radars, radios, electronically controlled weapons, and electronic navigational aids. It will show the direction from which the radiation is coming, and display and record the radiation so that it can be analyzed. From such analysis can be determined information such as the type of equipment radiating, what its function may be, and the number of transmitters involved. You can think of ECM as a kind of passive radar.

Other passive ECM methods are tactical evasion (to avoid detection by the enemy) and control of electromagnetic radiation by own ship (i.e., silence imposed on own-ship electronic transmitters) to avoid telltale radiation detectable by enemy ECM.

Active ECM includes those methods which the enemy can detect. In fact, its purpose is to impair the operation of the enemy's electronic devices (such as radar) by feeding them false signals. One method is jamming — radiating interferring or deceptive signals by electronic transmitters. The other is deception — using mechanical reflecting material to mislead his radars.

ECM does not have as important a role in weapon systems as optical devices, radar, and sonar do. Weapon systems can incorporate active ECM; there are gun and rocket projectiles designed to scatter radar-reflective material. Passive ECM may be used for direct guidance of weapon systems. The commonest present naval application of passive ECM is the use of intercept search in preliminary guidance of weapon system detecting equipment. Other passive ECM methods are used to prevent enemy interference with weapon system functioning.

SONAR

Radar cannot be used under water, because water absorbs radio waves. But water does conduct sound — better than air does, in fact. And sound is what the Navy uses to detect underwater targets.

It is possible to detect a submarine operating under power by merely listening — with the aid of a suitable microphone. But present-day submarine detection equipment more often functions somewhat like radar — it emits a pulse of sound energy, then picks up echoes. The equipment is called SONAR — SOund NAvigation and Ranging — and it not only detects underwater targets, but also locates them in terms of range, bearing, and depth.

The main units of the sonar equipment (fig. 13–6) are a transducer housed in a waterfilled dome (a streamlined housing protruding from the ship's hull) and console (STACK), manned by a sonarman. The stack periodically produces a powerful pulse of alternating current, which is transmitted to the transducer. The transducer converts the current into a pulse of high-frequency

sound (around 20,000 Hertz—one Hertz = 1 cycle per second) and projects it into the water. The transducer then switches to receive echoes, which are amplified in the stack. However, sound vibrations of 20,000 Hertz (Hz) are too high in pitch to be audible to people of normal hearing. Consequently, the stack's electronic circuits convert the echo to an easily audible 800-Hertz note, which the sonarman hears over the stack's loudspeaker. A visual indicator presents an image of sonar echoes as blips on the face of a cathode-ray tube (much as with radar). Additional sonar equipment determines the depth of the target.

Sonar is most frequently active—that is, an ultrasonic sound pulse is transmitted and the echo detected as described above. However, the sonar transducer can also be used to pick up sounds in the water, such as the sound of a submarine's propellers beating the water, the sounds of machinery in the submarine's hull, or sounds from subsurface animal life, such as whales grunting or squealing.

Sonar is the principal method now known for detecting underwater targets that are not themselves radiating sound signals. The principal factor limiting the success of antisubmarine warfare at this time is the limitations of sonar equipment. Although sonar is in some ways analogous to radar in the principle of its operation, it is more limited in range, less accurate in establishing target bearing and range, more severely affected by environmental factors such as variations in water temperature and flow at various depths, and is much more responsive to spurious echoes (as from schools of fish, wakes, air bubbles released by the target, and from the ocean floor or surface). Sonar echo interpretation (using both audible and visual responses) is exacting and requires much skill and experience.

Sonobuoys are used in one application of passive sonar. They are floating unmanned radio transmitters which lower microphones into the water and broadcast the sounds that they pick up. Sonobuoys are generally dropped by fixed-wing aircraft. Analysis of the sound pattern broadcast from several of them will indicate the location of sound-radiating submarines in the vicinity.

Sonar gear is carried aboard surface vessels and submarines. A special adaptation called DIPPING SONAR, in which the transducer can be lowered by cable from a helicopter, is used to supplement surface ASW forces.

MAGNETIC ANOMALY DETECTION

Any ferrous object will distort the earth's magnetic field. This distortion can be detected by a sensitive device—Magnetic Airborne Detection (MAD) equipment—that can either be towed by a ship or carried in an aircraft. At present, MAD gear is even more limited in range than sonar. Its principle of operation is applied also in guidance of some weapons.

DELIVERY DEVICES

Broadly, delivery devices launch, carry, or project a destructive device to the target. Examples are guns, torpedo tubes, rocket launchers, projectors, and depth charge racks. The term weapon is with one major exception properly applied to the destructive unit that is launched, carried, or projected. Thus, a rocket launcher is not, strictly speaking, the weapon in a weapon system, but the rocket itself is; the torpedo tube is not a weapon, but the torpedo is. The major exception is the gun. The gun is normally called the weapon in any system based on guns; a gun projectile generally is not called a weapon. Also, it should be noted here that gun systems are called batteries (e.g., 5" battery and 3" battery) and missile systems are called weapon systems (e.g., Tartar weapon system and Talos weapon system).

The term "delivery device" for such a weapon as an aircraft bomb or a ship-laid mine refers to the bomb rack and dropping gear or to the minelaying gear, not to the bomber aircraft or minelaying ship—which are vehicles.

FUNCTIONS OF DELIVERY DEVICES

To function effectively on their targets, all weapons (and projectiles) must either be directed to their targets or to the target area, or programmed so that they will operate properly in the target approach—or they may require both directing and programming. This is done by or through the delivery device either at or before the time of launching. Directing the destructive unit to the target may be done simply by aiming the delivery device (gun barrel or rocket launcher guide, for example). Or it may be done without aiming (as in torpedo tubes and missile launchers) by conveying program instructions into the weapon either mechanically or electrically. Programming

of functions to be performed by the weapon after launching (including the setting of devices which will initiate its explosion upon approach to or upon contact with a target) is done electrically in some weapons, mechanically in others.

Another function of many delivery devices is to propel the weapon or projectile over all or part of its course. Most mines and all aircraft bombs, for example, are conveyed to their targets by their vehicles, and the delivery device functions only to drop them.

TYPES OF DELIVERY DEVICES

Delivery devices now in use include:

1. Guns, which provide all the propulsion energy to their projectiles, direct them (by the position of their barrels), and program their functioning by adjusting some fuzes or causing them to arm (i.e., become set for action).
2. Rocket launchers, which direct rockets by positioning them. Similar launchers are also used with other weapons that are not classified as rockets.
3. Missile launchers, which position missiles for the initial stages of flight, and feed into them electrically steering and programming information up to the instant of firing.
4. Depth charge and thrown weapon projectors, which propel depth charges or thrown weapons to a selected point on the surface of the water. The weapons sink and function under water. The projectors may function on the principle of either the gun or the rocket.
5. Minelaying gear, which sets mines to perform arming and other functions after launching.
6. Bomb release gear, which initiates the arming process in bombs at the time of release.
7. Torpedo tubes and other launching devices, which set torpedoes to run in a specific direction, and may program them to arm at a specific range, undertake a selected search pattern, or perform other functions.

Some delivery devices which you may encounter on surface vessels will be discussed further in later chapters.

CONTROL UNITS

As previously defined, control units in a weapon system develop, compute, relay, and introduce data into a delivery unit, weapon, or both, in order to direct, control, or guide the weapon to the target and cause it to function in the desired manner.

The devices that perform these or allied functions, in whole or in part, include:

1. DATA TRANSMISSION SYSTEMS (generally electrical) to convey the target data developed by detecting units into the remainder of the system, to convey these and other data among the components of the system, and to convey aiming and programming data to the delivery device and to the weapon.

2. COMPUTER DEVICES (either mechanical or electrical, sometimes both) to process the input data from the detecting units and other sources and put out aiming and other programming data required to cause the weapon to reach its target and function at the proper time.
3. INDICATORS (sometimes called repeaters) to display data inputs and outputs as required at various locations on the ship.
4. DIRECTORS, which with the aid of detecting devices discussed earlier in this chapter establish target location, which may incorporate computer devices to function as described in No. 2 above, and which always incorporate data transmission components.

5. REFERENCE DEVICES, such as stable elements, which establish reference planes to stabilize lines of sight, aiming positions, etc. These are always gyroscopically stabilized though devices based on other principles may be used in emergencies.
6. ELECTRONIC CONTROL DEVICES intended to control guided missiles. These are generally radars or radio transmitters and receivers.

7. TRAINING AND ELEVATING GEAR. Most types of delivery units must be positioned to specific angles with respect to reference planes and lines in order to initiate correctly the launching of the weapon or projectile. This may be done through gear trains driven by hand, and this kind of manual operation is generally provided for emergency use or for adjustment of the equipment. In normal service, however, this function is performed by electric or electric-hydraulic power drives, controlled through data transmission systems by computers or directors. Training gear positions the delivery unit by rotating it in a plane parallel to the ship's deck; elevating gear positions it by rotating it in a plane perpendicular to the deck.

Table 2-1. — Table of weapon characteristics

Weapon or projectile	Propulsion characteristics	Guidance methods	Usual type of target	Delivery unit	Vehicle	Weapon control system
Gun projectile	Gun or rocket[1]	None, or guidance control	Air, surface, or land target	Gun	Aircraft or surface vessel	Gun fire control system or gun control system
Aircraft bomb	None	None, or guidance control	Surface or underground target	Bomb release gear	Aircraft	Bombsight
Rocket[2]	Rocket propellant	None, or guidance control	Air, surface, or land target	Rocket launcher	Aircraft or surface vessel	Special fire control system
Guided missile[3] and ballistic missile	Rocket or jet	All guidance methods	Air, surface, subsurface, or land target	Missile launcher	Aircraft, surface vessel, or submarine	Special fire control and guidance system
Depth charge[4] and other ASW thrown weapons	Gravity, gun type propellant, or rocket propellant	None (projected to depth), or guidance control	Submerged target	Release rack, gun type projector, or rocket launcher	Surface vessel	ASW fire control system
Torpedo	Screw propeller driven by electric motor or steam turbine; some types use rocket propulsion for initial stage	Gyroscopic, preset control, and homing, [illegible]	Surface craft and submerged targets	Torpedo or rocket launcher, torpedo tubes, [illegible]	Aircraft, surface vessel, or submarine	Torpedo or ASW fire control system
Mine[3]	[illegible]	[illegible]	Surface craft and submarines	Minelaying racks	Surface craft or aircraft	None, [illegible]

[1] [illegible]
[2] [illegible]
[3] [illegible]
[4] [illegible]

WEAPONS AND PROJECTILES

The end purpose of detection equipment, delivery units, and control systems is to get the destruction unit (weapon or projectile) to hit the target. It is then the function of the destruction unit to destroy or inflict maximum damage on the target. Except for small-size gun projectiles (those used in small arms, and those used in calibers up to 40-mm), most weapons and projectiles used in combat operation are loaded with explosive and equipped with devices to set off the explosive at the proper time. With some weapons and projectiles, the proper time is the instant the target makes physical contact with the weapon. With others (especially those designed to penetrate targets protected by armor or concrete) the proper time is after penetration. Still others are intended to explode when they are in the vicinity of the target.

ELEMENTARY WEAPON COMPONENTS

All weapons and projectiles have the following functional components, which take different physical form in different varieties:

1. A CONTAINER OR BODY which houses the other internal components. The body may have such other functions as piercing armor, breaking up into high-velocity fragments when the weapon or projectile explodes, or (by its streamline shape or by aerodynamic fins) improving ballistic characteristics.

2. A DETONATING DEVICE (called a fuze, pistol, exploder, detonator, etc.) which initiates explosion at the proper time, and includes safety devices to prevent explosion prematurely.

3. A BURSTER consisting of a quantity of explosive material. The main "payload" of the weapon may, more rarely, be a chemical agent, with a small amount of explosive to release or scatter it. Weapons for training purposes may contain still other payloads.

Weapons of some types have their own propulsion systems. The outstanding examples are guided missiles, torpedoes, and rockets. Gun projectiles, aircraft bombs, and most mines do not incorporate propulsion systems. Except for rockets, weapons with propulsion systems incorporate guidance and control devices.

CHARACTERISTICS OF WEAPONS AND PROJECTILES NOW IN USE

Table 2-1 summarizes in general terms the characteristics of the principal types of weapons and projectiles now in use. In interpreting the table, bear in mind that it is intended only as an aid in understanding the usual characteristics of contemporary weapon types. Some weapons combine the characteristics of more than one type, and don't fit neatly into the pigeonholes. Also be wary of nomenclature; e.g., some weapons not called rockets are at least in part rocket propelled.

CHAPTER 3

BASIC SCIENCES FOR NAVAL ORDNANCE AND GUNNERY

INTRODUCTION

This chapter may not be needed by all students because of its basic nature. It deals with the scientific principles — and particularly the practical applications of these principles — that should be part of the background of every junior naval officer. Without an understanding of these principles, a naval officer would be at a loss to comprehend the operation of even the oldest and simplest shipboard weapons. As for the new "sophisticated" ordnance, even the casual reader of newspaper headlines knows that our recently developed weapons demand a broad and sound scientific background.

This chapter will not, in and of itself, enable the reader to explain every detail of a specific weapon or installation. It should, however, prepare him to read, without great difficulty, the ordnance publications that do give complete details. It should also help him to understand a variety of standard components — such, for example, as gear trains — that are used in many types of machinery, ordnance and non-ordnance alike. Finally, it should help him to understand the general operational cycle (though not the fine details) of so complex a system as a train or elevation power drive.

For convenience, the chapter has been divided into separate sections dealing with mechanics, hydraulics, electrical devices, electronic devices, optics, and sound. In any specific ordnance device, principles from more than one of these areas are frequently combined.

Whenever practical, the illustrative examples have been selected from naval ordnance. Some types of ordnance equipment, however, are not well suited to serve as preliminary examples, so simplified examples have been used instead.

A reader who has studied general physics will recognize many of the topics in this chapter. He may also notice that the chapter passes lightly over large classes of conventional textbook material, and omits some classes altogether. An omission does not mean that a topic lacks importance. It simply means either (1) that the omitted topic is not closely related to ordnance problems or (2) that it will be covered later in this text, or possibly in another text.

Some readers may desire simplified explanations at the present time. Abundant supplementary reading in the background sciences may be found in the physics section of college libraries and in certain BuPers publications, such as: Fluid Power, NavPers 16193; Basic Machines, NavPers 10624; Basic Electricity, NavPers 10086; Basic Electronics, NavPers 10087; and Digital Computer Basics, NavPers 10088.

SOME FUNDAMENTAL DEFINITIONS

If one specialist is to understand another specialist correctly, the two men must agree exactly as to what they mean by certain important "technical" words. In the sciences, including physics, some of the specialized words are long and difficult. Frequently these long words have been derived from classical Greek or Latin — languages which, being "dead," are no longer subject to change. Or they may be derived from the names of renowned scientists of the past. This is especially true of units of measurement such as ohm, volt, and ampere.

Other scientific words look deceptively simple, for they have been taken from everyday speech. The scientist, however, does not use common words in a loose sense. He gives each a single precise meaning, thus restricting the word to one out of the many values it may have in social conversation. This meaning the student must learn and remember. Such words are generally used in this text in their precise scientific sense.

The paragraphs below give a few basic definitions that are used in the several branches of physics. Other definitions, more specialized in their applications, will be given in later sections of this chapter.

FORCE. A force is a pull or push on a material object that causes (or tends to cause) the object to move or (if moving) to change its direction or rate of motion. A force can be present even if no motion or changes in motion actually result from it. This can happen if the force is balanced by an equal force in the opposite direction. An example is a man standing on a floor. The floor exerts an upward force equal to the downward force exerted by the man.

PRESSURE is force per unit area. Obviously, the amount of pressure depends on two things—the amount of force and the area it's applied to. Imagine a 10-pound weight on your desk. It's applying a force of 10 pounds to the desk top. But what pressure is it applying? If the bottom of the weight has an area of 10 square inches, the weight applies a pressure of one pound per square inch. But if the bottom of the weight has an area of only one square inch, then it applies a pressure of 10 pounds per square inch.

WORK. As understood by the physicist, work is performed when (and only when) a force called an effort MOVES a material object against an opposing force called a resistance. Motion is the important idea in this definition. A seaman who simply stands and holds a 50-pound projectile may become tired, but he is not performing work in the physicist's sense of the word. But, if he lifts this projectile three feet in opposition to the 50-pound downward pull of gravity, he is working. The exact amount of work he does is 50 x 3, or 150 foot/pounds. In short, work is force acting through distance.

POWER. The word power, as used by the physicist, adds the idea of time to the idea of work. If our seaman hoists his 50-pound projectile 10 feet in 2 seconds, his power is $\frac{50 \times 10}{2}$, or 250 foot-pounds per second. Power, then, is the rate, or speed, of work. When time is important, as it usually is in combat, power becomes a major consideration. Many shipboard operations are mechanized because a machine has more power—that is, can move a heavier load in a shorter time—than the human labor available.

ENERGY. The capacity for doing work is known as energy. There are many sources of energy. The CHEMICAL energy released by a burning propellant moves a projectile toward its target. This chapter will be concerned with mechanical, hydraulic, electrical, radiant, and acoustic forms of energy.

A substance or mechanism that is ready to perform work, but is not actually performing it, has POTENTIAL energy. By virtue of their chemical composition, propellants and high explosives in magazine stowage have potential energy.

Energy in action is called KINETIC energy. A burning propellant has kinetic energy.

The total amount of energy in the world remains always the same (except that matter can be converted to energy in nuclear reactions). This statement is the law of the conservation of energy. Energy can be converted from one form to another, as when the kinetic energy of a waterfall drives a generator to produce electrical energy, which in turn drives a motor to produce mechanical energy. In any of these conversions, at least a small amount of energy becomes lost to the user, because radiation or internal friction causes it to be dissipated as heat. Designers of power equipment try to keep the incidental losses of energy as low as possible.

MASS. Mass is a fundamental property of all matter. In elementary terms, the mass of a body is the quantity of matter in it. When a force acts on a mass, it tends to move it or to change its motion (depending on the direction of the force). Gravity acting upon a mass at the earth's surface exerts a force tending to pull the mass toward the center of the earth. The amount of this pull we call weight. If we transferred the mass to the moon, whose gravity is only a fraction of the earth's, its weight would be different, but the mass would be the same.

INERTIA AND ACCELERATION. As we have said, it takes a force acting upon a mass to get the mass to move, or to change the mass' motion. In this sense, the mass resists the force. This property of mass is inertia. For a given force, the greater the mass, the greater the inertia and the smaller the change in motion. Any change in the motion of a mass is acceleration (speeding up) or deceleration (slowing down).

MOMENTUM. A mass in motion continues moving because of its inertia, and will resist forces that tend to stop it. This tendency to continue moving is momentum. Momentum is proportional to both mass and rate of movement, and is equal to their product. Thus a projectile weighing 5 pounds and moving at 2,000 feet per second has the same momentum as a motor launch weighing 2,000 pounds and moving at 5 feet per second. These are examples of momentum in masses moving in a straight line. A rotating mass also has momentum. In addition to the effect of its mass-inertia, the rotational momentum of a spinning mass such as a heavy-rimmed wheel will cause it to resist any force

that tends to change the direction in which its axis of rotation is pointing. This is why a top remains upright as long as it maintains sufficient rotational speed. This effect constitutes the operating principle of the gyroscope, described in the next section of this chapter.

CENTRIFUGAL FORCE. This is a special case of inertia. Any spinning object develops a centrifugal force. The rim of a turning wheel, for example, pulls outward on its spokes. The strength of the centrifugal force varies as the square of the speed at which the wheel is turning. For double the speed of rotation, for example, the centrifugal force will increase four times; for triple the speed, the centrifugal force will be nine times as great.

NEWTON'S LAWS OF MOTION

Sir Isaac Newton is famous for his enunciation of the law of gravitation, but equally fundamental in physics are his three laws of motion. These are the basis for the sciences of mechanics and ballistics. A clear understanding of them and their applications is essential for the realistic comprehension of any mechanical device or system. The laws are:

1. First law. A body at rest tends to remain at rest and a body in motion tends to continue moving in a straight line unless (in either case) the body is acted on by some unbalanced force. (In applying this law to practical examples about you, always remember that friction, gravity, and air or water resistance must be taken into account).

2. Second law. A body acted on by an unbalanced force will accelerate in the direction of the force, and the acceleration will be directly proportional to the unbalanced force and inversely proportional to the mass of the body. (Note that this idea has already been presented implicitly in the preceding article's discussion of acceleration and momentum. In fact, the law can be restated more briefly in terms of momentum.)

3. Third law. To each action there is an equal and opposite reaction. ("Action" here is the force which body No. 1 exerts on body No. 2; reaction is then the force which body No. 2 exerts on body No. 1. A book lying on a table exerts a push downward on the table equal to its weight; the table's reaction pushes the book upward with equal force. The rotating screw of a ship pushes the water rearward; the water reacting against the screw exerts an equal forward push. The combustion chamber and exhaust nozzles of a rocket exert backward thrust on the exhaust gases; the gases react with an equal forward push on the rocket.)

BASIC PRINCIPLES OF MECHANICS

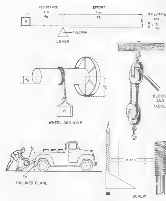
All machinery—no matter how complex it may be—can be broken down into simple components or basic mechanisms. These include the lever, the wheel and axle, the pulley (block and tackle or block and falls in Navy parlance), the inclined plane, the screw, the gear, the shaft, the cam, the spring, the clutch, the pawl and ratchet, the piston and cylinder, the friction brake, the roller or ball, the bearing, and so on. Some of these are actually applications or rearrangements of others. (Examples: the wheel and axle is a special type of lever; a screw is a special type of inclined plane.)

Figure 3-1 shows representative examples of five of these basic mechanisms. They illustrate one objective—to do work or transmit motion by moving a load (often called the resistance) through application of force or effort. (Or the force may be used in the mechanism to counterbalance another force.)

Historians and others have attempted to reduce all mechanical devices to six (or some other number) "basic machines," but since different lists include different mechanisms, and frequently omit mechanisms as important as those they include, we shall concentrate on those particularly applicable to ordnance devices, without attempting to develop universal generalizations or niceties of classification.

ANALYSIS OF CERTAIN BASIC MECHANISMS. The lever principle is probably the most basic one in mechanics. The drawing of the lever (fig. 3-1) shows that a resistance acting at one side of the pivot or fulcrum can be counterbalanced by an effort applied at the opposite side. (In this particular class of lever, the effort is a downward push.) The distance from the fulcrum to the point at which the push of the resistance seems to be concentrated (that is, to the center of gravity of the resistance) is called the resistance arm. The distance from the fulcrum to the effort is called the effort arm.

Balance is achieved when the product of the effort and the effort arm becomes equal to the product of the resistance and the resistance



110.4
Figure 3-1. — Five basic mechanisms.

arm. This principle is called the lever formula. It may be expressed mathematically as follows:

$$R \times d_R = E \times d_E$$

in which E = effort,
R = resistance
d_E = effort arm,
d_R = resistance arm.

(Not all texts use the same symbols for the two arms, but all texts teach the same fundamental relationship.)

The ratio $\frac{R}{E}$ (which, as is easily shown, is equal to d_E/d_R) is the theoretical mechanical advantage of a machine. In actual practice the mechanical advantage is always lower than the theoretical figure, since part of the effort must be consumed in opposing the machine's internal resistance, or friction.

The wheel and axle can be analyzed as an application of the lever idea. By the term "wheel and axle" the physicist does not mean a wheel that turns about an axle, as in a wagon. He means, instead, a wheel (or part of a wheel) and a shaft that are firmly secured to each other and turn as a single unit. The ordinary doorknob is a wheel and axle in the physicist's sense. So is the crank, which is really a single spoke that acts like a wheel when it is turned. In a wheel and axle, the effort arm is the radius of the wheel (or wheel segment) that the operator turns. The product $E \times d_E$ is known as torque or twisting force, and is expressed in pound-feet, ounce-inches, or similar units. The tool called a torque wrench acts automatically to warn the operator when he has applied the set value of torque to a screw.

Not all basic mechanisms are applications of the lever. The inclined plane is the basis of the wedge, of the screw (i.e., the mechanical component, not the fastening device), of some types of cam, etc. To understand the relation between the screw and the inclined plane, note how figure 3-1 shows that in effect a screw is an inclined plane wrapped around a cylinder, as the hypotenuse of the paper triangle is wrapped around the pencil. The pitch of the screw (P in the illustration) is the distance between threads. A screw must make a complete turn to move a load along a resistance arm equal to P.

The gear principle is the act of meshing teeth to permit mechanical engagement of rotating and reciprocating mechanical components. This makes possible the linking of a number of individual components such as screws, wheels and axles, etc. A wheel becomes a gear when its rim is cut to form regularly spaced teeth that mate with corresponding teeth on another wheel. Usually (but not necessarily) the shaft is firmly fixed to its gear. Gears and shafts will be discussed later in the chapter.

Though they can be—and often are—used alone, the basic mechanisms are frequently combined to form machines or mechanical systems. The next article will deal with these more complex systems.

MECHANICAL SYSTEMS

There are two major classes of mechanical systems—driving machines (often called prime movers) and driven machines. An electric motor is a driving machine; a sump pump powered by the motor is a driven machine. In many small, compact ordnance devices, such as bomb fuzes, compressed springs act as driving mechanisms.

Some machines act simultaneously as driving and driven components. The pump in a gun's electric-hydraulic drive is driven by an electric motor. The pump, in turn, acts to drive a hydraulic motor, and this motor drives the training or elevating devices.

There must always be some connecting link to transmit power between a driving machine and a driven machine. When the two machines are near each other, the link is frequently a mechanical one, such as a belt, a chain, or a system of shafts and gears. Under some conditions, enclosed fluids are used to transmit mechanical motion. This use of fluids will be taken up in the section on hydraulics. When the driving and the driven machines are widely separated, electrical transmission is normally used.

BASIC PURPOSES. All mechanisms serve one or more of the following purposes:

1. They may transmit motion, force, or power. As already mentioned, belts, chains, and gearing systems are used for this purpose.

2. Mechanisms with a high mechanical advantage are used to increase a small force to a large one, at a corresponding sacrifice of speed and distance. By using the block and tackle shown in figure 3-1, a man can hoist an 80-pound weight by giving a 40-pound pull. But, to hoist this weight 12 feet, he will have to haul in 24 feet of line.

3. Provided a low mechanical advantage (some fraction less than 1) is acceptable, a machine can increase the speed and extent of motion. If a crank 10 inches long acts through a common

shaft to turn a wheel 20 inches in radius, a point on the rim of the wheel will travel twice as many inches, in a second, as the crank does. Since the effort arm, this time, is only half the resistance arm, the applied effort will have to be double the resistance.

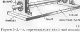
4. Finally, a machine may change direction or type of motion. In the lever shown in figure 3-1, a downward effort moves the resistance upward. As will be shown later, gearing systems are effective in changing the direction of motion, and even in converting circular motion to straight-line motion, or vice versa.

PRINCIPAL COMPONENTS. The paragraphs following deal with the principal components of complex mechanical systems. As will soon become evident, these components are either basic mechanisms or connecting devices.

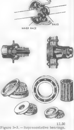
A SHAFT is a cylindrical rod used to transmit turning motion. A shaft may be pinned to input or output gears, or it may have splined or toothed ends that mesh with gears. A shaft is mounted to turn without interfering with other components. Figure 3-2 shows a common type of shaft mounting used in mechanical computational devices.

One shaft may be joined to another by a rigid sleeve, by a flexible coupling, by a universal joint (described later under pivots), by gears, pulleys, or clutches, etc.

BEARINGS permit rotation of a shaft with respect to a support that does not rotate with the shaft. A plain or journal bearing (not illustrated) uses a sleeve within which the shaft turns. To reduce friction, the sleeve is generally of softer metal than the shaft. Ball and roller bearings (figure 3-3) substitute rolling friction (which is comparatively small) for sliding friction between surfaces. Thrust bearings are designed to take



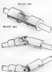
12.49
Figure 3-2.—A representative shaft and mounting.



12.50
Figure 3-3.—Representative bearings.

up an axial thrust while permitting shaft rotation. There is a variety of thrust bearing designs. Jewel bearings are used in very fine machinery. The pointed end of a hard steel shaft rotates in a V-shaped depression in the fixed jewel (usually a sapphire or ruby).

A PIVOT is a fixed pin or short axis that permits one part to turn with respect to another. Pivots are closely related to bearings. The main distinction between them is that pivots are generally associated with limited arcs of rotation. An arrangement of pivots called a universal joint (fig. 3-4) is used to connect rotating components (for example, a pair of shafts) that must be permitted to swivel as they rotate.

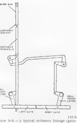


5.34
Figure 3-4.—Pivoting arrangement in a universal joint.

A CRANK is an arm (or pair of arms) keyed to a shaft in such a way as to impart or receive motion. The common exterior or side crank is manually rotated to introduce hand inputs into a mechanical system. As mentioned earlier, this is essentially one spoke of a wheel. Internal cranks take various forms. One of the commoner forms found in naval ordnance is the bell crank shown in figure 3-5. This type is used to carry push-pull motion around corners. Cranks may also be used to convert turning motion to back-and-forth (reciprocating) motion (for example, in certain types of motor-driven reciprocating pumps) or vice versa (for example, in internal combustion engines).

A LINKAGE is a system of bars, cranks, and other lever-like components, connected to fixed members and to one another in such a way that an input force causes a desired movement of the movable members. Figure 3-5 shows a linkage used in the loader for the 3-inch rapid-fire gun. When the vertical shaft moves upward, the horizontal gates are pulled together to close; when it moves down, they open.

Of all the mechanical components used in ordnance machinery systems, few are more numerous or more varied than the gears. They are used to transmit motion, to change the direction or type of motion, and to increase or decrease



110.5
Figure 3-5.—A typical ordnance linkage (gate-operating linkage, 3-inch rapid-fire gun loader).

speed. Also, as a later article will explain, they are used to perform the four arithmetical processes (addition, subtraction, multiplication, and division). The serious student will regard the discussion of gears in this chapter as a mere introduction to a large and fascinating topic.

As has been said before, many (but not all) gears are wheels with teeth that mesh and permit one wheel (the driving gear or driver) to turn the other wheel (the driven gear) without slipping.

Figure 3-6 shows a simple gearing arrangement. Here the driver and the driven gear have the same diameter and the same number of teeth. Necessarily, therefore, they turn at the same speed, though in opposite directions (one clockwise and one counterclockwise). The shafts,

5.22.1
Figure 3-6. — Spur gears with a 1:1 ratio.

likewise, turn at the same speed and in opposite directions.

The ratio of the number of teeth on the driver to the number of teeth on the driven gear is called the gear ratio. In figure 3-6, the gear ratio is 1:1.

Gears that have radial teeth, as in figure 3-6, are called spur gears.

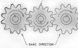
A designer may wish two parallel shafts to turn in the same direction. They will do this if he places an idler between the driver and the driven gear, as shown in figure 3-7. This idler serves only to change the direction of motion; it has no other use in the system.

To produce a difference in speed between two gears (and the related shafts) the designer makes the driven gear larger or smaller than the driver, as required. If the driven gear has four times the circumference (and four times the number of teeth) of the driver, it will take four times as many seconds to make a complete revolution; that is, its speed will be a quarter of the speed of the driver.

To turn a driven gear and shaft faster than a driver, as is frequently desired, the designer makes the driven gear smaller than the driver. The smaller gear of a meshing pair is frequently called a pinion.

The shafts in a gearing system need not be parallel. As figure 3-8 shows, they may be placed at right angles or at some other desired angle. Bevel gears (fig. 3-8) can be designed to transmit motion at almost any angle. Bevel gears that are at right angles are called miter gears.

Some gears do not need to turn through a complete circle. The mechanism may have limit stops that restrict the travel of a pinion to a certain number of revolutions clockwise and an equal number counterclockwise. To save space and weight, the gear driven by this pinion can be a segment, or sector gear, rather than a circle. Figure 3-9 shows a sector gear.



12.55
Figure 3-7. — The principle of the idler gear.

5.22.4
Figure 3-8. — Bevel gears.

5.24.6
Figure 3-9. — How a sector gear saves space.

Under some conditions a limited-travel gear need not be an arc. Sometimes it can (and indeed MUST) be a straight bar with gear teeth, or a rod with a specially designed screw thread. The bar-type gear is called a rack (fig. 3-10); the screw-type gear is called a worm, and its mating gear is called a worm wheel (fig. 3-11).

A single-thread worm turns its worm wheel one tooth for each turn of the worm, and a double-thread worm turns its wheel two teeth for each turn of the worm. Worms may have three, four, or more threads. The number of wheel teeth turned for each revolution of the worm always corresponds to the number of threads on the worm.

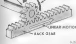
Worms are often used where great reductions in amount of rotation are needed, because the ratio of rotation between the worm and its wheel is usually large. Since each thread of the worm moves only one tooth of the wheel the gear ratio between worm and wheel is:

$$\frac{\text{The number of threads in the driving worm}}{\text{The number of teeth in the driven wheel}}$$

In a single-thread worm with a 100-tooth wheel, the worm must make 100 revolutions for one complete turn of the worm wheel. (The gear ratio is 1:100.)

Sometimes the worm wheel drives the worm. This is possible only when the slope of the worm threads is greater than 5°.

The rack converts rotary motion to linear motion when it is driven by a pinion. A rack with two sets of teeth may serve simultaneously as a driver and a driven gear. When the rack drives,



5.22.13
Figure 3-10.—A rack makes conversions between rotary motion and linear motion.

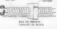
5.22.9
Figure 3-11.—A worm and worm wheel.

the mechanism converts linear motion into rotary motion.

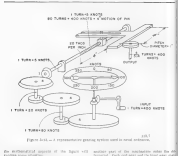
Another device for converting rotary motion to linear motion is a screw with a traveling block (fig. 3-12). The block is restrained in such a way that it cannot turn with the screw. As the screw turns, the block walks along the threads. Screw-type elevating gear in older gun turrets uses this principle, which has other ordnance applications.

Figure 3-13 shows spur gears of several sizes, bevel gears, a screw with a traveling block, a rack (the T-shaped member) moved backward and forward by this block, and, finally, a gear that converts the straight-line motion of the rack to rotary motion. For the sake of simplicity, the draftsman has not shown the teeth on the various gears.

The input enters this system through the handcrank. The designing engineer has assigned an arbitrary input value of 400 knots to each complete revolution of the handcrank. Numerals indicate the gear ratios other than the 1:1 ratio of the first pair of bevel gears. The figure is introduced at this time to show a representative but fairly simple example of the gearing and shafting used in naval ordnance. Somewhat later,



110.6
Figure 3-12.—The principle of the travelling block.



115.7
Figure 3-13. — A representative gearing system used in naval ordnance.

the mathematical aspects of the figure will receive some attention.

A DIFFERENTIAL is an arrangement of gears and shafts that accurately and continuously combines two variable inputs to produce a single output or, conversely, as in the rear end of an ordinary automobile, breaks a single input into two outputs that vary as required.

In figure 3-14 a typical differential has been partially cut away to show the four bevel gears and the spider shaft that are the heart of the mechanism. This is a common differential design, though there are others.

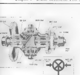
The simplified drawings in figure 3-15 will clarify the relationships within the differential.

The two bevel gears on the sides of the differential are its end gears. Each end gear is firmly joined to a corresponding spur gear. This spur is the input gear through which inputs from another part of the mechanism enter the differential. Each end gear and its input gear make up a side of the differential.

The two bevel gears above and below, meshing with the end gears, are the spider gears. The cross shaft and the spider gears make up the spider. The cross shaft is pinned to a long shaft called the spider shaft.

The spider gears are not pinned to the cross shaft in the usual gear-and-shaft relationship. Instead, these gears are free to rotate about their shaft on precision bearings. Likewise the two sides are free to rotate independently about the spider shaft. The output gear of the differential, however, is securely pinned to the spider shaft and rotates with it.

Figure 3-16 shows how the spider gears work. When a side receives an input, the input gear and its attached end gear turn. This action



12.87
Figure 3-14.—A typical differential.

drives the two spider gears, and in so doing turns the spider and the spider shaft, with its attached output gear.

If only one of the two sides receives an input, the opposite end gear will remain stationary while the two spider gears walk around it. The output will then vary with the single input.

If both sides receive inputs in the same direction, the movement of the spider will be proportional to the sum of the two inputs.

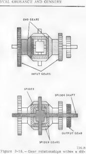
If the two sides receive inputs in opposite directions, the movement of the spider will be in the direction of the larger input, and will be proportional to the difference between the two inputs.

If the two inputs are equal and opposite, the spider gears will turn, but the spider shaft will not move.

Because the spider gears are free to roll between the two end gears, the revolutions of the spider always represent half the sum (or difference) of the two inputs.

This short description has shown that the differential can be used to perform additions and subtractions. In fire control devices it is used for that purpose.

Like a gear and shaft, a CAM is a mechanical device for receiving inputs and transmitting outputs. As will be shown later, cams are capable of showing mathematical relationships that cannot be expressed in terms of simple gearing and shafting.

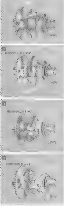


110.8
Figure 3-15.—Gear relationships within a differential.

Cams vary greatly in design. Every cam, however, has some sort of shaped surface—a groove, a ridge, or a contour—that is positioned by the input force. Every cam has also an output device, called a follower, that bears against the shaped surface and is positioned by it.

One type of cam has a uniform spiral groove. Each point on this spiral corresponds to an output that is directly proportional to an input from the driving pinion shown at the lower right in figure 3-17. The cam follower is the small cylinder shown as a phantom in the illustration.

The cam shown in figure 3-17 can rotate either clockwise or counterclockwise, depending on the direction of the input. Rotation in one direction forces the follower (and with it the



110.9
Figure 3-16. —How a differential works.

attached follower block and the output pin outward from the center, along the straight-line slot. A reversal of the direction of rotation forces the follower back toward center. Though the follower itself never touches the zero position at the exact center of the cam, the output pin is offset enough to allow a zero reading to be taken.

This cam is a positive-action type. This means that its follower is keyed to the groove in such a way that it is forced to move every time the cam moves. Some cams, however, have followers that move only when they are held against the cam by gravity, spring action, or some other force that is free to operate only at some stages of the mechanical action.

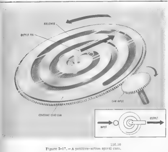
Cams can be used to control or position other mechanisms. Shipboard guns, for example, have firing cutout cams that act to interrupt firing when the gun is pointing in a direction that endangers permanent shipboard installations. But many cams are special-purpose mathematical devices. As such, they will be discussed in the next section.

MECHANICAL COMPUTING DEVICES

The problem of hitting a distant, rapidly moving target from a maneuvering ship is much too complicated to be solved by mental arithmetic or even by hand-operated slide rules. When a conventional gun is fired, some two dozen factors may enter into the fire control problem. (For a discussion of the fire control problem see chapter 6.) If the weapon is a guided missile and the target is a manned aircraft or a guided missile moving at supersonic speed, the problem is still more complex and the futility of longhand methods is obvious.

MACHINES CAN SOLVE THE PROBLEM. As the reader has probably noticed, certain basic mechanisms can hardly be described, even in their simplest terms, without some reference to their potentialities as problem solvers.

In figure 3-13 the designer of the gearing and shafting decided arbitrarily that one revolution of the input crank should represent 400 knots. He could have selected any other figure, had he found it better suited to his purpose; a crank revolution, as such, has no mathematical significance until one has been assigned. When an input value has been selected, however, every



110.10
Figure 3-17.—A positive-action spiral cam.

transmitted value in the entire gearing system varies with the input, following the fundamental law of proportion:

$$a:b = c:d.$$

A GEAR TRAIN, then, is one means of representing mathematical relationships.

Unfortunately, many factors in the fire control problem do not vary in accordance with the laws of direct proportion. These factors, too, can be expressed in terms of mechanical motion. By using the basic mechanisms described thus far, plus certain specialized modifications of these mechanisms, the Navy's mechanical computers set up and solve problems that involve algebra, trigonometry, and even calculus. Related mechanisms either position the gun or launcher automatically or give operating personnel the information they need.

TYPES OF COMPUTERS. A computer may be of the digital or the analog type. It may be mechanical, electrical, or a combination of both. We are here concerned only with mechanical computation. (For some further discussion of fire control computers using electrical or electronic elements, see chapter 6.)

A digital computer essentially performs the basic arithmetical processes—addition, subtraction, multiplication, and division—by counting. The ordinary office calculating machine is a mechanical digital computer.

An analog computer represents mathematical relationships by analogous mechanical motions and positions. These may vary from moment to moment by large or small amounts, but the solution is produced continuously. Its output at any given instant measures the values at that instant of the two or more changing quantities in the problem it has been designed to solve. A simple example will help to make this clearer. Suppose the hypotenuse of a right triangle remains constant in value but the two acute angles are continuously changing. One of the computing devices described later in this section will tell the operator (or the related computing mechanism) the exact values of the base and altitude of this triangle, whenever these values are needed in the solution of a larger problem.

For solving the fire control problem, the mechanical analog computer is much faster than any combination of mechanical digital units. It is not as versatile as a digital computer, but a fire control computer is required to deal only with fire control problems. The fact that it is not adapted to other problems is not a drawback.

The following tabulation lists some of the shipboard computing devices (usually mechanical or electromechanical analog types) that a junior officer is likely to encounter, in gun systems:

Fire control computers
Gun directors
Gun elevation indicators
Gun train indicators
Parallax correctors
Rangefinders
Rangekeepers
Receiver-regulators
Sightsetter's indicators
Stable elements
Stable verticals
Star-shell computers
Wind transmitters

In torpedo and ASW systems:

Course directors
Depth computers
Attack directors
Range recorders

Later chapters will explain the functioning of many of these computing devices. The paragraphs following will take up a number of their representative mechanical components and tell briefly how they work.

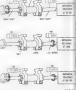
ADDING AND SUBTRACTING DEVICES. As was explained earlier, the output of a differential (figs. 3-14, 3-15, 3-16) measures the sum or the difference of two inputs.

Finely constructed mechanisms with light loads sometimes use a compact jewel differential that has spur gears instead of bevel gears. The operating principle is exactly the same as in the bevel type.

A shaft can be designed to add some selected constant to the value it would normally transmit. Figure 3-18 shows a two-shaft combination arranged to transmit an output of range-minus-50.

Each shaft in figure 3-18 has a mechanical counter showing its output. In the first view, the two shafts have been zeroed, coupled, and turned as a unit until the output of each is 50 yards.

In the center view, the crankshaft remains clamped to the sleeve coupling, but the input shaft has been unclamped and reset at zero. When the loose clamp is tightened again and the two shafts turn as one, the variable introduced by the crankshaft will be reduced by 50 when the input shaft transmits it. For example, in the



110.11
Figure 3-18. — A coupling used to introduce a constant.

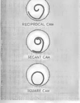
lower view, a crankshaft reading of 150 yards is transmitted by the input shaft as 160 yards.

This use of a sleeve coupling is called "putting a constant offset on the line." The offset can be either negative, as here, or positive.

CAMS, MULTIPLIERS, AND DIVIDERS. The use of shafting and gearing in solving problems in ratio and proportion has already been explained, and it is an extremely important use.

By the use of cams, quantities that vary according to other laws can frequently be introduced into the gearing, either for transmission to a dial or for further use in solving the problem.

A great many mathematical relationships can be expressed, accurately and compactly, as graphs on squared paper. It is possible to construct cams that reproduce these graphs. The spiral cam in figure 3-17 is only one of a great variety of possible types. Three commonly used cams are shown in figure 3-19.



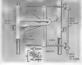
5.29
Figure 3-19.—Some representative computing cams.

In computing cams, such as the three shown in figure 3-19, the output is a function of the input; that is, it varies with the input, but not in direct proportion. The output of the reciprocal cam is one-divided-by the input. The input of the secant cam is the value of a given angle; the output is the secant of that angle. Cams can, of course, be cut to represent other trigonometric functions. The square cam multiplies the input by itself. The subject of cams is much broader and more complex than this necessarily limited paragraph would indicate.

Sometimes cams cannot be designed to show the output values for all possible inputs; but they can still be used to take care of inputs within certain ranges that are adequate for the needs of the system.

The SCREW-TYPE MULTIPLIER shown in figure 3-20 is a device that computes, continuously and accurately, the product of two continuously changing input values. Actually there are several types of multipliers, but all of them make use of the laws of proportion as exemplified by a pair of similar triangles.

The multiplier illustrated here receives one of its inputs through a slotted slide that is walked out from (or back toward) its zero position by two screws that are turned by bevel gears. The second input enters through a slotted arm that pivots on a stationary pin, and is joined at its opposite end to an input rack.



12.91
Figure 3-20.—A screw-type multiplier.

In its zero position, the pivot arm is perpendicular to the input slide. The pivot arm is forced away from (or back toward) its zero position whenever the input rack is moved by the input spur gear.

A multiplier pin passes through the slots in the input slide and the pivot arm. This pin also passes through a third slotted member—the T-shaped output rack.

Whenever the input to the slide, the input rack, or both is zero, the multiplier pin will lie at some point along the zero line shown in figure 3-21. The slot in the output rack will also lie along the zero line. This is correct, since any quantity multiplied by zero equals zero.

Whenever the input slide and the input rack BOTH move from their respective zero positions, the multiplier pin will be above the zero line by a vertical distance that, as will be shown in the next paragraph, measures the product of the two inputs. The output rack will be displaced by this same amount, and will transmit the measured product as its output.

Figure 3-22 shows how this particular multiplier utilizes geometric truths. In this figure, the constant K is the distance, along the zero line, from the stationary pin to the vertical line of travel of the right end of the pivot arm. Solid line a is the distance the input rack has moved from zero. Dotted line b is the distance the input slide has moved to the right of zero. Dotted line x is the distance the multiplier pin and, with it, the input rack has moved up from zero.

Notice that these relationships define two similar right triangles, one superimposed on the other. Since the corresponding sides of similar triangles are in proportion,

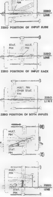
$$\frac{x}{a} = \frac{b}{K}$$

and

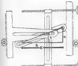
$$x = \frac{ab}{K}$$

That is, x, which represents the output, is the product of the two inputs, divided by a constant. A proper choice of gearing ratios can remove the effect of the constant.

In actual practice, to save space, a multiplier is often designed to deliver a fixed fraction (say a tenth) of the whole product. Gearing converts this fraction to the full value.



12.92
Figure 3-21.—How the multiplier works.



12.93
Figure 3-22.—Similar triangles in the multiplier.

INTEGRATORS. In some phases of the broad fire control problem—and in many other situations as well—a quantity that obeys the laws of proportion (and therefore can be transmitted by a gear) must be multiplied by a second quantity that varies at a constantly changing rate of change. We say that the second quantity accelerates, or decelerates, or changes by increments. The integrator, one type of which is shown in figure 3-23, is a device that performs this special kind of multiplication.

The horizontal disc is driven at a constant speed that measures the non-accelerating input. A gear-and-rack arrangement receives the accelerating or decelerating input and uses this input to drive a movable carriage backward or forward along a selected diameter of the disc. The carriage contains two balls, one directly above the other, that are free to turn.

Except when it is above the dead center (zero point) of the disc, the lower ball rotates whenever the disc turns. The speed of the ball depends on two factors—the constant speed of the disc itself and the variable point at which the carriage is positioned at the given instant. The nearer the ball is to the edge of the disc, the faster it will rotate.

The lower ball drives the upper ball. (The designer uses a pair because the two balls roll more smoothly than a single one. In other designs a single ball or a roller can be used.) The rate of rotation of the balls measures the product of the non-accelerating input and the accelerating input. The upper ball drives a roller which, in turn, transmits its constantly varying output to the next stage of the gearing system.

At one side of the center of the disc, the balls transmit positive values; at the opposite side, negative values.

COMPONENT SOLVERS. A vector is a line drawn to show both the direction and the magnitude of a force. Such quantities as target speed and wind motion are shown on graphs as vectors. For practical purposes, a vector can be treated as the diagonal of a rectangle that has one corner at the zero point of a conventional graph, one side along the x-axis, and one side along the y-axis. These sides of the rectangle represent the two components that make up the vector.

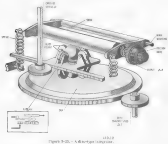
The two components can be computed by simple trigonometric methods. When it is desirable to perform this operation automatically, a component solver computes the desired values and transmits them.

Figure 3-24 shows the operating principle (but not all the structural details) of a typical component solver. The dial carrying the compass rose and own-ship outline can be rotated about the zero point of the graph. This dial is set at an angle representing the relative target bearing (angular offset of own ship's centerline from the line of sight). The vertical pin is positioned at a distance from center that represents own ship's speed. Thus the vector is established.

Two L-shaped slides, arranged as shown in the illustration, are slotted to receive camming action from the vertical pin. The slides move whenever the pin moves, but they are so mounted that the range slide always moves parallel to the line of sight and the deflection slide always moves perpendicular to the line of sight. The distances travelled by the two slides always measure the values Xo and Yo, which are the two quantities this particular component solver is designed to transmit.

A mechanical component solver can resolve a vector rapidly; but a wire-wound resolver, constructed on the principles of the synchro, can receive an input that measures the vector and instantaneously transmit a pair of outputs that measure the components.

NOTE: In addition to elaborate gearing and shafting, and also in addition to a large number of electrical devices, the Mark 1 computer, a World War II design, contained 9 component solvers, 10 integrators (representing two types) 15 multipliers (both simple and complex types)



110.12
Figure 3-23. – A disc-type integrator.

8 cams, 24 handcranks, and more than 150 differentials.

GYROSCOPES

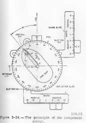
A gyroscope (colloquially called a gyro) is fundamentally a rapidly spinning wheel. Its rotational momentum gives it two useful properties:

1. rigidity in space
2. precession

The first property was described earlier as being caused in any rotating body by its rotational momentum. It can be demonstrated easily in a toy gyroscope (figure 3-25, part A) which, when spinning rapidly and supported at one end, will appear to defy the law of gravity by remaining horizontal while the other end is unsupported.

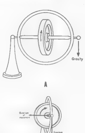
At the same time, though, the gyro will demonstrate the effect of the second property, precession, by rotation in a horizontal plane about its point of support, as shown in part B of figure 3-25. Gravity pulls the unsupported end of the spinning gyro wheel's axle vertically downward. But the axle doesn't move downward; instead it reacts by moving horizontally (i.e., at 90° to the pull of gravity).

To understand precession, consider the spinning mass of the large wheel shown in figure



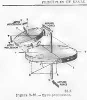
110.13
Figure 3-24.—The principle of the component solver.

3-26. An applied force symbolized by thick arrows labeled APPLIED FORCE (at the top and bottom of the wheel's axle) tends to tip the axle (i.e., rotate it about the axis Y-Y). Particle A is part of the spinning wheel's rim. At some instant its inertia is moving it in the direction AC, But the applied force tends to move it in the direction AB. It cannot move in two directions at once. It responds to the two forces acting simultaneously upon it by moving in the direction AD. But to do this the wheel's plane of rotation must shift as shown in the smaller diagram in figure 3-26. If the wheel's plane of rotation shifts, so does its axis of rotation (X-X). This shift is at an angle of 90° to the axis of the applied force (Y-Y). By turning figure 3-26 on its side and comparing it with figure 3-25, part B, you can see how the force of gravity pulling the axle downward can cause the axle to move horizontally.

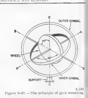


4.99:.100
Figure 3-25.—Elementary gyro action. A. Rigidity in space; B. Precession.

The gyro's first property (rigidity in space) makes it desirable to use for establishing a reference direction (as in a torpedo or gyrocompass) or a reference plane (as in a stable element). In these applications the gyro wheel is so mounted that it will not be affected by changes in the direction of the vehicle that carries it. Since the precessional force is related to the deflecting force applied to the gyro, its second property (precession) is used (in lead-computing fire



88.6
Figure 3-26. — Gyro precession.



4.101
Figure 3-27. — The principle of gyro mounting.

control equipment) when it is necessary to determine the amount of lead required for a gun projectile to hit a moving target. These applications are discussed in later chapters of this text.

In these applications, it is necessary to mount the gyro wheel with the amount of freedom required in each case. This is done by using gimbals. A gimbal is a metal ring (or part of a ring) supported so that it can rotate about an axis formed by two points 180° apart on its circumference. Figure 3-27 shows a gyro wheel supported in two gimbals so that it has three degrees of freedom.

The gyro rotor is free to spin on its axis A-A. That's one degree of freedom. The rotor axis is supported in bearings in the inner gimbal ring, which is free to turn on the axis B-B. That makes two degrees of freedom. The outer gimbal, pivoted on the support, is free to turn on axis C-C. That gives the gyro its third degree of freedom. With three degrees of freedom, the gyro can maintain its rigidity in space no matter how its support moves.

PRINCIPLES OF HYDRAULICS

DEFINITIONS

Fluids are materials that continuously adapt their shape to fit their containers. Fluids include both liquids and gases. In this section the main emphasis will be on liquids.

Hydraulics, in the strict sense, deals with the behavior of liquids in motion through a closed (that is, liquid-filled) system of connected containers. In its practical applications, hydraulics is concerned with the uses of fluid-filled systems in transmitting applied forces and producing or controlling mechanical motion.

A closely related science, called hydrostatics, deals with the behavior (including especially the pressure aspects) of fluids at rest in open containers. These may be such large "containers" as lake or ocean beds. In actual practice, the Navy man ordinarily expands hydraulics to include hydrostatics. Following are some definitions used in hydraulics.

HYDROSTATIC PRESSURE. Any liquid in an open container exerts pressure equally in all directions from any given point within the liquid. The degree of pressure on a submerged object varies directly with the depth the object has reached. At a depth of one foot in sea water, the bottom of a mine case is under hydrostatic pressure of 64.3 pounds for each square foot of its surface. At a 10-foot depth, the pressure is 10 times as great, or 643 pounds per square foot.

Underwater weapons — particularly mines and many depth charges — have various components that remain inactive until the hydrostatic pressure on the exterior of the device becomes great

enough to overcome a built-in resistance, such as that offered by a spring or an expanded bellows.

APPLIED PRESSURE. A liquid in a closed system also exerts hydrostatic pressure, but this is not a major consideration in any component except the storage reservoir. This reservoir must contain enough liquid (and exert enough pressure or head) to keep all the enclosed spaces filled during a complete cycle of operation.

The really important fact about pressure in a closed system is the capacity of the liquid for transmitting—rapidly and in all directions—a force that is applied to one component of the system. Because it can do this, an enclosed liquid can be used, much as a basic machine is used, to overcome resistances and move loads.

BASIC PRESSURE-MOTION RELATIONSHIP. The system shown in figure 3-28 is not equipped to produce a work output that has any practical value outside the classroom. It does, however, have teaching value in that it shows the basic principle behind many more elaborate and highly practical systems.

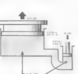
In figure 3-28 a total downward force of 25 pounds is applied to the small piston, whose head has an area of 5 square inches. The pressure applied through this piston to the enclosed liquid is 25 pounds for each 5-square-inch area of container surface. The unit pressure is, therefore, 25/5 or 5 pounds per square inch. (This unit pressure may be abbreviated 5 psi; the latter symbol is pronounced p-s-i, not like the name of the Greek letter Psi.)

The input, transmitted equally in all directions throughout the liquid, acts on the large piston head with an upward pressure of 5 psi. The large piston head has an area of 250 square inches. It is, therefore, subjected to a total upward force of 250 × 5, or 1250 pounds.

The system is similar, in effect, to a lever in which E is 25, R is 1250, and the theoretical mechanical advantage is 50. But, just as in the lever, the distances travelled by the effort and the resistance are in inverse proportion.

For example, if the small piston moves downward an inch, it displaces 5 cubic inches of practically incompressible liquid that must be accommodated somewhere unless the system is to burst. The large piston is the only component that can move to make room for the displaced liquid; but it needs to move upward only 5/250 or 1/50 inch to accommodate the 5 cubic inches of fluid.

This system lacks some of the essential components of a useful hydraulic mechanism. The next article will mention and briefly explain those components.



110.14
Figure 3-28.—The basic principle of hydraulic pressure.

SYSTEM COMPONENTS

FLUID RESERVOIR. Because certain working members of a hydraulic system move up and down or in and out, the amount of space inside the system varies. To keep the available space filled at all times, the system must have a storage tank or reservoir to accommodate back-up fluid and return it to the system as needed. The depth (or the elevation, which amounts to the same thing) of the storage reservoir must be designed to furnish enough hydrostatic pressure or head to keep all enclosed areas filled during a complete cycle of operation.

PISTONS AND CYLINDERS. Figure 3-28 shows elementary examples of the working parts present, in one form or another, in all hydraulic mechanisms. These are the cylinders that accommodate varying amounts of fluid and the pistons (short, closely fitted interior cylinders) that move, in response to mechanical or hydraulic pressure.

Usually the piston is attached to a rod that projects through a leakproof opening in the capped end of the enclosing cylinder. The usual purpose of the rod is to receive a mechanical input or to transmit an output.

CONNECTING LINES. The system must have connecting lines joining the working components to one another and to the reservoir. These lines, like the one connecting the two cylinders in figure 3-28, may sometimes be part of a single casting. If the working elements are a distance apart, pipes are used to connect them.

VALVES. A workable hydraulic system must have valves that open and close to keep the fluid moving in the right direction, in the right amounts and at the proper pressure. The valves must also prevent the liquid from moving away from certain areas until it has accomplished its work. A lack of valves robs the device in figure 3-28 of practical value.

There are many types of valves, varying from extremely simple to fairly complex designs. Some have stems that permit an operator to admit fluid, to cut it off, or to allow flow at a reduced rate. Others are operated by the internal pressures that develop within the system. At this time only a few valves of the simpler sort will be considered.

The COCK is a plug-type valve permanently seated within a pipe. A cylindrical opening in the plug can be turned at will, to permit flow or to block it. Figure 3-29 shows the top view of a typical cock.

A GATE VALVE, like a cock, can be turned by an operator to admit or obstruct flow. Instead of staying within the pipe in its open condition, the gate valve occupies a projecting "bonnet," as shown in figure 3-30.

A NEEDLE valve has a tapered point to permit gradual opening or closing in an area when a more sudden change of pressure would be dangerous.

A CHECK valve, responding automatically to pressure changes within the system, opens to permit flow in one direction and closes to check or prevent flow in the opposite direction. Spring or gravity action sometimes hastens the closure of this valve. Figure 3-31 shows a check valve hinged at the top to allow flow toward the right and prevent flow toward the left. A check valve is sometimes called a directional valve.

A SAFETY or a RELIEF valve (the two types are similar but not identical) is a spring-loaded check valve that keeps an exhaust or blow-off pipe closed until an excessively high pressure within the main line overcomes the built-in spring resistance and opens the valve.

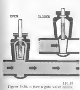
SPOOL valves and ROTARY valves may, depending on design details, be operated by hydraulic or electrical actuators, or may (less frequently) be hand-operated. These valves are used in more complex hydraulic systems to direct fluid flow as desired for system operation.

SIMPLE PRACTICAL APPLICATION

Before taking up the pump, the reader may be interested to see that the addition of devices described thus far — a storage reservoir, a connecting line, two check valves, and a gate valve — can turn the device shown in figure 3-28 into the highly useful hydraulic jack shown in figure 3-32 and, somewhat later, in figure 3-33.

110.16

Figure 3-29. — How a cock controls flow.



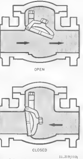
110.16
Figure 3-30.—How a gate valve opens.

The valves numbered 1 and 2 in the illustration are check valves. Valve 1 is hinged at its left-hand side. It is open because fluid under pressure has been forced against its lower face by the down stroke of the small piston. When open, this valve admits displaced fluid to the large cylinder. Valve 1 cannot swing downward beyond its horizontal or closed position.

Valve 2, shown closed in figure 3-32, is hinged at the top. It opens by swinging toward the small cylinder. It cannot swing open in the direction of the storage tank. This valve is closed by the pressure exerted during the down stroke of the input piston, for this applied pressure exceeds the hydrostatic pressure exerted on the opposite face of the valve by the liquid in the storage tank.

Valve 3, the GATE valve, is kept closed while the operator is using the jack to lift a load. Acting as a pair, valves 1 and 3 keep the displaced fluid trapped in the large cylinder. Upon completion of his work, the operator opens valve 3, thus allowing the displaced fluid to return to the reservoir as the large piston sinks by gravity to its normal position.

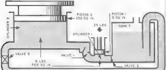
Figure 3-33 shows the relationships within the jack during the up stroke of the input piston. As this piston is pulled upward, the pressure within the small cylinder drops, and a partial vacuum is formed. The hydrostatic pressure of



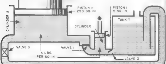
11.319(110)
Figure 3-31.—The operating principle of the check valve.

the fluid in the storage tank forces valve 2 open and lets fluid enter the small cylinder as long as the piston is rising.

Because the pressure in the small cylinder has dropped below that in the large cylinder, the large piston tries to drop and restore balance; in technical language, the large piston exerts back



110.17
Figure 3-32. — A hydraulic jack — down stroke of the input piston.



110.18
Figure 3-33. — A hydraulic jack — up stroke of the input piston.

pressure, forcing valve 1 downward to its horizontal or closed position. Because this valve cannot swing below the horizontal, it simply remains closed until it is opened (and valve 2 is closed) by the next input stroke.

The cycle shown in figures 3-32 and 3-33 is repeated until the liquid trapped in the large piston has lifted the load as high as the operator wishes, within the capabilities of the jack.

THE SIMPLE PUMP. A pump is a mechanism that uses an external source of power to apply force to a fluid. All pumps in open hydraulic systems take advantage of the fact that the earth's atmosphere, a gaseous fluid, exerts a static pressure whose existence becomes noticeable whenever a partial vacuum is created.

Anybody who drinks through a straw is making use of this phenomenon. By sucking on the straw, he creates a partial vacuum. Atmospheric pressure, acting on the liquid in the tumbler, forces enough of it up the straw to dispel the partial vacuum.

In a common hand pump, figure 3-34, the lever-type pump handle is joined to a piston rod with a simple upward-opening check valve (numbered 1) in the piston. The downstroke of the piston applies pressure to the water in the pump, opening valve 1 and closing another check valve (numbered 2) at the base of the pump.

On the up stroke of the piston, pressure is reduced, and a partial vacuum is created, in the area between the two valves. Valve 1 closes. Atmospheric pressure in the well forces water up the pipe. The upward thrust of the water opens valve 2 but is not strong enough to open valve 1 as long as the piston continues to rise. The

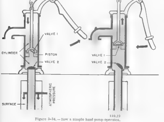


Figure 3-34. — How a simple hand pump operates.

excess water thus drawn into the pump flows from the spout.

There is a great difference in structure, though not in fundamental operating principle, between the simple hand pump in figure 3-34 and the Waterbury constant-speed, axial-piston, variable-delivery pump that constitutes the A-end of a gun's electric-hydraulic train or elevation power drive. The summary below will prepare the way for the description of the A-end in the next section.

SOME FACTS ABOUT PUMPS. Pumps that are designed to perform work operations are installed as integral parts of closed hydraulic systems in which fluid from a reservoir is repeatedly circulated by pump action. These pumps are divided into two main classes — the reciprocating and the rotary type.

RECIPROCATING pumps deliver liquid by a back-and-forth movement of mechanical parts. ROTARY pumps deliver liquid by a circular (or other curved) motion of mechanical parts. The A-end is a reciprocating pump. The following numbered statements apply to it.

1. By lengthening or shortening the work stroke of its piston(s), a reciprocating pump can be made to deliver a larger or smaller volume of liquid per stroke.

2. Reciprocating pumps can be constructed to utilize two, three, or even many piston-and-cylinder units arranged in a cylinder block and driven by an ordinary power motor.

3. An AXIAL-PISTON reciprocating pump has a cylinder block that rotates on a central shaft in such a way that the pistons move back and forth in a direction parallel to the shaft.

4. A VARIABLE-DELIVERY axial-piston pump contains a means of varying the piston stroke (and thereby varying the output of the pump) automatically in response to control signals.

ACCUMULATORS. An enclosed hydraulic system usually contains an accumulator that stores a certain amount of fluid under air pressure. When there is a sudden heavy demand for fluid, in excess of the capacity of the pumps, fluid from the accumulator enters the system and tends to equalize the flow.

ORDNANCE HYDRAULIC MECHANISMS

This article will take up, in rather general terms and without fine details, some of the hydraulic devices that are found associated with gun mounts, turrets, and missile-launching systems. Because the way has already been prepared for it, the hydraulic pump or A-end will be described first.

HOW THE A-END WORKS. Instead of having a single piston like the ordinary hand pump, the A-end often has nine piston rods, each with its own cylinder. These cylinders are arranged in a cylinder barrel that rotates in a fixed plane perpendicular to its central shaft.

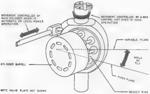
The ends of the cylinders are joined to a socket ring that rotates with the cylinder barrel, but at the same time tilts at an angle that can be varied from 20° on one side of the position of zero tilt to 20° on the other side. A universal joint, similar in principle to the one shown in figure 3-4, allows the socket ring to be driven and tilted simultaneously. The amount and direction of tilt depend on the control signal the A-end receives.

The simplified drawing in figure 3-35 shows one possible angle of tilt between the cylinder barrel and the socket ring. The yoke-like structure in which the socket ring is bearing-mounted is called the tilt box. The ring is tilted in accordance with signals from the indicator-regulator.

When the A-end is in operation, the cylinder barrel rotates in the vertical plane, and the socket ring rotates with it, at an angle determined by the input signal. Unless the cylinder barrel and the socket ring are exactly parallel, each piston rod, during a complete cycle, will be pushed into its cylinder (thus increasing the internal pressure) for a half-cycle and then will be drawn toward the opposite end of the cylinder (thus reducing the internal pressure) for the next half-cycle. The cylinder barrel as a whole will have a high-pressure side and a low-pressure side.

To get pumping action, then, it is only necessary to arrange pipe lines and valve ports in such a way that hydraulic fluid can always be drawn into the cylinders as the internal pressure decreases and can always be forced out as the pressure increases. The valve plate shown in figure 3-36 makes the necessary arrangements.

To minimize leakage, the rotating cylinder barrel bears closely against the fixed valve plate at all times. For the angle of tilt shown in figure 3-36, the lower pipe line is the intake and the upper line is the output. Lands, corresponding to the neutral-pressure (9 o'clock and 3 o'clock) positions of the cylinders (figure 3-36, part A) prevents short-circuiting of the two sides. When the angle of tilt reverses, the high-pressure side



110.20
Figure 3-35.—Angle of tilt in the A-end.

becomes the low-pressure one, and the direction of flow reverses. Figure 3-36, part B, shows the assembly in phantom.

In some installations, the B-end or hydraulic motor is separated from the A-end as shown in figure 3-37. In others, the B-end is directly connected to the valve plate. In either event, the action of the two ends is the same.

B-END. The B-end, shown as a phantom in figure 3-36, is much like the A-end in design, except that the angle of tilt is built in and cannot be changed. The valve ports on the intake side receive oil under pump pressure from the A-end. This oil exerts forces at right angles to the faces of the pistons open to the intake ports. These forces can each be broken into two components—(1) a thrust component along the axis of rotation that serves no useful purpose and is neutralized by bearings and (2) a turning component that rotates the socket ring and, with it, the cylinder barrel and the output shaft.

After a given piston has taken all the fluid it can from the intake side of the valve plate, it passes the land and begins to discharge fluid through the outlet ports of the B-end to the intake (suction) side of the A-end.

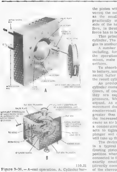
The direction of turning of the B-end and its output shaft depend on the direction of turning of the A-end.

RECOIL AND COUNTERRECOIL DEVICES. The recoil and counterrecoil systems of naval guns operate without pump or motor action. Details of these piston-and-cylinder systems vary with the sizes and types of guns. Figure 3-39 is a representative sketch, based on a conventional 5-inch gun.

The recoil cylinder contains fluid and has a piston whose head is precision-fitted to the cylinder wall. The counterrecoil cylinder contains air (or some inert gas) under pressure and has a partially hollow plunger whose outer end extends through an airtight fitting in the end of the cylinder.

The recoil and counterrecoil units work together to keep the "kick" of the gun within reasonable bounds, to restore the gun to battery, and to hold it there until the next round is fired.

If the student understands two simple and useful hydraulic devices — the hydraulic recoil brake



110.21
Figure 3-36. — A-end operation. A. Cylinder barrel, valve plate, and socket ring. B. Phantom view of assembly.

and the differential cylinder — he should be able to study, with little difficulty, the specific recoil-counterrecoil mechanisms in any naval gun.

In a hydraulic recoil brake, the head of a piston fits closely within a fluid-filled cylinder. The passages from one side of the piston head to the other are few and small. These passages may be holes through the piston head, or they may be grooves in the cylinder wall. If an applied force (such as the shock of firing) acts to move the piston with respect to the cylinder (or vice versa) the movement can take place only as fast as the small passages allow fluid (which is practically incompressible) to flow from one side of the head to the other. Movement, therefore, is throttled, because much of the applied force has to be used up in overcoming resistance.

This principle is applied in the gun's recoil cylinder. The design features may vary from one gun to another, but the purpose remains the same.

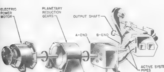
A number of other ordnance braking devices, including, for example, the dashpots that delay the operation of certain linkages in moored mines, make use of the throttling effect of small orifices.

To absorb the final shock as the gun returns to battery, some guns have a dashpot-type counter-recoil buffer that is physically associated with the recoil cylinder.

As previously mentioned, the counterrecoil cylinder contains air or possibly some inert gas. (Gases, of course, are fluids; but unlike liquids they are capable of being compressed under pressure. When the pressure is removed, they expand. As can be seen in figure 3-38, recoil movement decreases the amount of space in the counterrecoil cylinder, thus putting the air under greater than normal pressure. In many guns the increased internal pressure would tend to cause an air leak, except for the sealing effect of a comparatively small differential cylinder that acts to tighten the packing through which the plunger rod extends. The next few paragraphs will take up the differential cylinder.

The device in the lower part of figure 3-38 is a typical differential cylinder. The free-floating piston in this cylinder always takes a position where the thrust of the air (directly connected to the air in the counterrecoil cylinder) exactly counterbalances the thrust of the oil (directly connected to the oil gland at the center of the chevron packing). But part of the area of the oil side of the differential cylinder head is occupied by the end of the piston rod, and therefore cannot receive thrust from the trapped oil, whereas the entire area of the air side of the head receives thrust from the trapped air. Therefore, at all times, the pressure in terms of pounds per square inch on the oil side must be greater than the corresponding pressure (in psi) on the air side.

Whenever recoil action raises the air pressure, the unit pressure of the oil — including, of course, the oil in the packing gland — rises proportionately. Thus the oil at the center of the specially shaped packing acts to "inflate" it and



110.22
Figure 3-37. — The hydraulic speed gear.

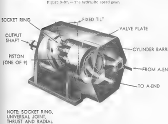


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Figure 3-38. — A phantom view of the B-end.

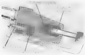

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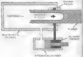
Figure 3-39.—Representative recoil and counterrecoil systems.



84.148
Figure 3-40.—Principle of the differential cylinder.

prevent leakage of air. Any leakage that occurs will be an oil leak, not an air leak.

As soon as the recoil action is completed, the air in the counterrecoil cylinder begins to expand and return the gun to battery. The oil side, of course, continues to exert greater unit pressure than the air side, and therefore acts to seal the counterrecoil plunger.

BASIC PRINCIPLES OF ELECTRICITY

Electricity is a form of energy. As such, it can be harnessed to do work.

Electrons make electricity available for use. Normally an electron revolves within a parent atom, somewhat like a planet within a solar system. Every electron bears an electric charge. If not free from its atom—whether by chemical action or by other means—the electron takes its charge with it.

All substances have resistance, which is a tendency to block the movement of free electrons. Conductors have a relatively low resistance; insulators, a high resistance. The unit of resistance is the ohm. In electrical equations, R represents resistance in ohms.

CURRENT is a stream of free electrons moving through a conductor. Current flows when (and only when) there is a closed circuit from the current source back to the source. Current is measured by the number of electrons that pass a given point in a second. The unit of current is the ampere. In equations, I stands for current in amperes.

Each point in an electric circuit has a potential or an electromotive ("electron-moving") force that corresponds roughly to head in a water system. Electromotive force is commonly abbreviated emf; its unit is the volt. In equations, E stands for an emf in volts. The emf at any point is mathematically equal to the product of the current and the resistance; this principle is called Ohm's law. It may be expressed in three equations:

$E = IR$, or by simple algebra,

$I = \frac{E}{R}$, and

$R = \frac{E}{I}$.

The unit of electric power is the watt. The power in watts is equal to the product of the current and the voltage. P is the symbol for power in watts. It may be expressed in the equation:

$P = EI$, or, by substitution from Ohm's law,

$P = E \times \frac{E}{R} = \frac{E^2}{R}$, and

$P = IR \times I = I^2R$

Electric current is of two types — direct and alternating. In direct current (d-c) the electrons move continuously in one direction, though not necessarily at a constant speed. In alternating current (a-c) the direction of electron movement reverses rapidly and repeatedly. The number of times the electrons reverse in one second is called the FREQUENCY. Navy ships commonly use frequencies of 60 Hz (Hertz) or 400 Hz. One hertz is equal to one cycle per second.

Electricity and magnetism are closely related. Any conductor carrying electric current is surrounded by a magnetic field.[1] Furthermore, a magnet will induce a voltage in any conductor that is moved in its magnetic field. Conversely, if a current-carrying conductor is placed in a magnetic field, the conductor will tend to move at right angles to the field.

When a conductor is twisted into a coil and energized by current, the coil, as a unit, has a magnetic field. When the field of an energized coil is changing in strength (because of a change in current), it can induce a voltage in a second coil that is not physically joined to the first one.

A TRANSFORMER is designed to make practical use of induction. In the transformer a current-carrying coil, called the primary, induces a voltage in another coil or group of coils, called the secondary.

An induction device called the synchro is taken up later in this chapter.

SOURCES OF ELECTRICAL ENERGY

Batteries and generators are the two usual sources of electric current. A battery uses chemical energy to produce electrical energy that becomes usable when an external conductor is joined to the two pole pieces of the battery. Batteries are used to energize the small, self-contained electrical systems in flashlights, independent mines, some depth charges, and numerous testing devices. Larger batteries are used to operate electrically driven torpedoes. (See chapter 13.) Very large installations are designed to furnish propulsive power for submarines. Batteries produce direct current only.

A GENERATOR uses mechanical energy (as from a steam or gasoline engine) to produce electrical energy by causing relative motion between an armature and a powerful magnetic field.

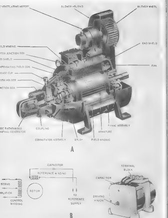
In most d-c generators the armature is the rotor, or turning member, and the magnetic field is furnished by the stator, or stationary member. Alternating current is always produced in the armature windings. In d-c generators the armature windings are connected to a commutator on the armature shaft. Stationary brushes on the stator contact the rotating commutator so as to receive electrons moving in one direction only. Thus the commutator-brush arrangement converts the a-c armature output to direct current.

Some a-c generators are constructed much like the d-c generator, except that they use solid annular insulated slip rings (instead of segmented commutators) and brushes. These directly transfer the a-c output to the external circuit. Larger a-c generators, however, use rotors with d-c excited electromagnets fed through brushes and slip rings, while the armature windings are in the stator. In still another variation, some special-purpose a-c generators have neither slip rings nor brushes; in these all windings, both armature and field, are in the stator, while the rotor consists of a metal core. The a-c damping generator mentioned below is of this kind of construction.

Figure 3-41, part A, shows the amplidyne train drive motor assembly on a 5-inch gun mount. The amplidyne system will be described in a later section, but this part of the figure is intended chiefly to illustrate examples of two types of motor and a d-c generator.

In general, ordnance systems do not generate electricity except for relatively small control voltages employed in "damping" (stabilizing) the operation of servosystems. In the amplidyne system, which is a d-c servosystem, the stabilizing voltage is generated by a small d-c generator (labeled "tachometer generator") mechanically connected to the shaft of the main drive motor. As you can see in the figure, the generator possesses the armature, field, commutator, and brushes mentioned above. In this illustration the tachometer generator is too small to show all these features clearly, but the student can inspect the corresponding features (which are similar in appearance and construction, though larger) in the main d-c drive motor.

[1] A piece of iron or other magnetic material may have its own permanent magnetic field independent of any electrical current. This phenomenon, as distinct from the magnetic field surrounding a current-carrying conductor, is discussed further in chapter 12 in connection with degaussing.



73.161

Figure 3-41.—Generators and motors. A. Amplidyne train motor assembly. (Note the d-c tachometer (damping) generator on the left and the a-c ventilating motor on the top of the assembly.) B. Typical small a-c instrument servo motor and its circuit diagram.

Small a-c damping generators (not illustrated) are used in some a-c servosystems. In external appearance as well as internal construction they resemble the servomotor illustrated in figure 3-41, part B; or they may be built on cylindrical rather than square-ended frames.

MOTORS

Structurally, motors in general resemble generators. A motor has a fixed stator and a rotor that can revolve. Instead of producing current, the motor receives current and uses it to energize its windings and produce torque. In nearly all types of motors, the torque normally causes the armature to revolve. In all large motors (i.e., larger than a fraction of a horsepower) locking or stalling the rotor so that it cannot turn when the motor is energized by its rated voltage will burn out either the motor or its current source, if not protected by fuses (and burnouts can often occur even with fuse protection, too). Some small specialized types of motors are designed to withstand locked-rotor currents. In one such type of motor, called a torque motor, the rotor can turn only a few degrees in normal operation; in other types it is expected that the rotor will stall for a time in normal service.

Motors used in ordnance gear always have the field winding in the stator; if there is an armature winding, it is in the rotor. With the rare exception of some machines that use permanent-magnet fields, d-c motors always have armature windings, commutators, brushes, and field windings. The main train drive motor shown in figure 3-41, part A, is a d-c motor with these components.

In all motors, the rotor is driven by the interaction between the magnetic fields produced by the stator and those produced by the rotor. In nearly all d-c motors and many a-c motors the interacting magnetic fields are produced by currents fed to the rotating armature windings and to the stationary field windings. In some a-c motors, however, currents are fed only to the field. The fluctuating magnetic fields produced by the a-c field currents induce other currents in the rotor; in turn, the induced rotor currents develop magnetic fields that interact with those of the field to develop motor torque. Motors that function on this principle are called INDUCTION MOTORS. The armature for such a motor may consist of a cage-like copper structure imbedded in a laminated soft iron core (these are called "squirrel-cage" motors), or of an aluminum or copper cup surrounding an iron core. Large a-c induction motors may have rotors with coil windings (these are called "wound-rotor" induction motors).

There are, in contrast to the restricted number of fundamental types of electric generators, a great variety of types of electric motors (including a-c, d-c, and "universal" motors operating on either type of current), some of them quite different in principle from others. The types most frequently encountered in ordnance equipment are:

1. Polyphase a-c induction motors. These are the large motors, developing from 5 to over 100 horsepower, used to operate gun power drive electric-hydraulic and amplidyne systems, hoists, rammers, and the like. Figure 3-37 shows such a motor. As a class they are characterized by high starting torque and fairly constant speed under varying load.

2. Single-phase a-c induction motors. These have different characteristics from polyphase motors, but work on similar principles. They comprise the fractional horsepower motors used to operate small blowers, windshield wipers, etc. The blower motor in part A of figure 3-41 is an a-c single-phase squirrel-cage induction motor.

3. Synchronous a-c motors. (Not illustrated.) Synchronous motors can be very large (they have been used to drive ship's screws) but in ordnance equipment you will find only very small induction-type units designed to drive light loads, such as computing mechanisms, at absolutely unvarying speed. On most ships a special a-c constant-frequency supply is provided to drive such motors since they can hold a constant speed only in so far as the frequency of their a-c supply remains constant.

4. Servomotors. The function of the servomotor will be explained later in this section. Its important characteristics are that (1) it must be reversible when its input is reversed, (2) it must develop (for its rating) substantial starting torque, and (3) its output torque must be at least roughly commensurate with its electrical input. (These characteristics are by no means applicable to all types of electric motors.) Servomotors used in ordnance equipment are nearly always of either of two main types:

a. A-c instrument servomotors. These are small fractional-horsepower induction motors powered by two inputs—(1) the ship's a-c power supply and (2) the output of the servoamplifier.

Figure 3-41, part B, illustrates one type of a-c servo motor and its circuit. The motor is always directly geared to the load, which may be a small indicator or computing mechanism component, a synchro, etc. (Synchros will be discussed later in this section.) It may also be geared to an a-c damping generator. Conventionally, the motor has two windings. One, the reference winding, is continuously energized by the ship's a-c supply (which is often called the REFERENCE VOLTAGE.) A capacitor is usually in this circuit. The other winding receives the amplifier output, which is an alternating current of the same frequency as the reference supply, but differs in phase from the current in the reference winding. This means that at any instant, it will differ in magnitude and often in polarity from the reference supply. In most servomotor circuits the capacitor functions to develop this phase difference. When only the reference supply is fed to the motor, its rotor (which has no winding but is only an aluminum or copper cup, shell, or cage secured to the output shaft) will not turn. When the amplifier puts out a current, the motor will develop a torque whose direction will depend on the phase relationship between the reference and amplified output currents. Since the power developed by a-c servomotors is quite small, the motor output may itself be used to control a hydraulic servo which develops greater power.

b. Direct current mount power drive motors. These motors are high-powered units used as described below in conjunction with amplidyne generators to drive gun mounts in train and elevation. The main drive motor shown in figure 3-41, part A, is of this type.

POWER TRANSMISSION

In a small electrical system, like that in a torpedo or mine, the power source, the transmission lines, and the simple or elaborate operating equipment must all be scaled down to fit a limited space. In an electrical system serving a city or a countryside, the power demands are heavy, and large-size components are necessary. Alternating current from huge generators may be transported for long distances over high-voltage lines. Transformer stations, making practical use of the principal of induction, convert the current and voltage to values safe for industrial and residential use.

Shipboard electrical systems occupy a position somewhere between these two extremes. The ship's main generators, connected to a cable system through two or more switchboards supply current for many routine uses. T total power available must be great enough t meet the demands of varying conditions, i cluding battle.

All possible safety precautions are observ The cables pass through special packing gla between one ship unit and the next. Junctio and splices are made through special boxes terminal boards. Tests are frequent and thoro

Turrets and mounts have their own very ela orate wiring systems. Specific wiring system are described in the NavOrd publications (O and OD) for the ordnance installations.

ALTERNATING CURRENT

In alternating current, as previously me tioned, the direction of electron movement r verses rapidly and repeatedly. Though s applicable, Ohm's law no longer deals with si ple resistance as the single obstructive eff that limits current flow at a given voltage. In a circuits, specific types of circuit elements al have other obstructive effects on current fl and those effects vary with the a-c frequen These effects are called CAPACITANCE and I DUCTANCE, and in any a-c circuit they must taken into account along with resistance. The effects are not restricted to obstruction of cu rent flow; as we previously noted in connecti with the explanation of the capacitor in a servo motor operation, they can change t phase of one a-c voltage with respect to anothe

In addition, there are still other ramificatio to this subject. Though they are important detailed consideration of the functioning of a electrically operated ordnance equipment, the aspects of a-c theory are beyond the scope this course. Junior officers assigned to com munications or fire control will find that enlisted men specializing in these fields a well grounded in theory, as well as in practical applications. The ordnance publica tions on specific items of equipment frequent cover those aspects of the theory that are a sumed to be new in the reader's experienc

SYNCHROS

A synchro is an a-c energized device th looks like a small motor or generator, but closer in operating principle to the transforme All synchros have a wound rotor and a wou

stator, with slip rings and brushes to connect the rotor windings to the remainder of the system.

In terms of functioning principles, there are five types of synchro:

Synchro transmitter
Synchro receiver
Synchro control transformer
Synchro differential transmitter
Synchro differential receiver

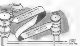
Any synchro system includes two or more of these units, one of which must be a synchro transmitter. Synchros are made in standard sizes and electrical characteristics, in two main varieties — one designed for operation at 60 Hz, the other variety designed for operation at 400 Hz. Principles of functioning apply regardless of difference in size and frequency rating. To understand these principles, we'll discuss first a system comprising a transmitter and a receiver, then go on to the other types.

SYNCHRO TRANSMITTERS AND SYNCHRO RECEIVERS. A synchro transmitter (also called a synchro generator) transmits an electrical signal that varies with the angle of rotation of its shaft. This signal goes through three conductors to a synchro receiver (also called a synchro motor). An additional pair of conductors furnishes excitation voltage from the a-c reference supply to both the receiver and the transmitter. See figure 3-42. The synchro receiver responds by causing its own shaft (if not too heavily loaded) to rotate through an angle corresponding to the signal. The two shafts turn through the same angle and in the same direction (for example, both 30° clockwise or both 15° counterclockwise, and so on). See figure 3-43.

The two drawings in figure 3-43 show how a transmitter or receiver (these are electrically similar) is constructed. The stator contains three evenly spaced, electrically connected coil windings. The centrally located rotor is also wound as a coil. The rotor winding is excited by the a-c reference supply.

When alternating current flows in the rotor, it creates a rapidly reversing magnetic field. This field induces currents in the stator coils; the stator currents produce fields whose total effect, or resultant, at any given instant, directly opposes the field of the rotor.

To form a conventional transmitter-receiver arrangement, two synchros are wired as shown in figure 3-44. Normally, however, the distance



12,156
Figure 3-42. — An elementary synchro system.

separating the synchros is much greater than the drawing indicates.

In their at-rest position, the two synchros are as shown in part A of the illustration. An input (through gearing or a handcrank) turns the rotor of the synchro transmitter as shown in part B. This upsets the balance of the magnetic fields throughout the system.

In restoring the system to magnetic balance, the electromagnetic forces acting on the synchro receiver turn its rotor to a position corresponding exactly to the position taken by the rotor of the transmitter. See part C of figure 3-44.

When the signal changes again, this sequence of events is repeated.

A synchro receiver of the type just described can be connected through shafting and gearing to turn a very light load, such as a dial. It is not powerful enough to turn a heavy load like a gun mount or a missile launcher. A special kind of synchro receiver called a control transformer can, however, act through a motor to turn a fairly heavy load.

SYNCHRO CONTROL TRANSFORMER. Like the basic synchro receiver, the control transformer receives an electrical input signal from a synchro transmitter. In the control transformer, however, the rotor is designed to produce an output voltage proportional to the incoming signal. After being amplified, as shown in figure 3-45, this output voltage drives a motor (called a servomotor) that operates a gearing system to turn the load.

SYNCHRO DIFFERENTIALS. Two types of synchros used in fire control are similar in

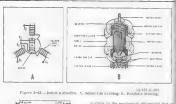


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Figure 3-43. —Inside a synchro. A. Schematic drawing; B. Realistic drawing.

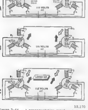

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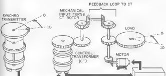
Figure 3-44. —A representative synchro system.

purpose to the mechanical differential that continuously adds or subtracts two changing inputs.

The synchro differential transmitter (also called a differential generator) receives two inputs: (1) a mechanical signal that turns its rotor and (2) an electrical signal that is fed into its stator windings. The output of this synchro is an electrical signal that exactly measures the sum (or, if wired for this purpose, the difference) of the two inputs.

The synchro differential receiver (also called a differential motor) combines two electrical signal inputs to produce a mechanical output. This output consists of a rotor torque or movement that accurately represents either the sum or the difference of the two inputs.

USING PAIRS OF SYNCHROS. The accuracy with which a synchro receiver or control transformer will duplicate the signal from the transmitter is on the order of a few minutes of arc difference between the signal as transmitted and the signal as received. In some applications a few minutes' inaccuracy is not important, but in others it is. For high-precision applications, a pair of synchro transmitters is geared together in the ratio of 36:1, and is connected electrically to a pair of receivers or control transformers similarly geared together. In each pair, the unit that rotates more slowly is the low-speed or coarse unit; the other is the



12.157
Figure 3-45.—A-c instrument servomechanism. Pictorial functional schematic.

110.24
Figure 3-46.—Basic servosystem.

high-speed or fine unit. You can liken this arrangement to the hands of a clock, with the clock hands geared 36:1 rather than 12:1. The hour hand corresponds to the coarse or low-speed indicator, and the minute hand to the fine or high-speed indicator. When pairs of synchros are used, the coarse unit covers the full range with which the system deals, while the fine unit, which rotates a number of times for one rotation of the coarse unit, makes it possible to transmit with much better accuracy than would be possible with the coarse unit alone.

SERVOMECHANISMS

WHAT THEY ARE. Electrical arrangements that cause mechanical action to take place automatically in response to synchro signals are called followups or servomechanisms. A servomotor is one of the components of a followup.

A servomotor is a reversible motor that operates in a slave-to-master relationship with the synchro equipment from which it receives its input signals. There are both a-c and d-c types of servomotors. The one mentioned later in this chapter, in connection with amplidyne power drives, is a d-c type. Certain dials and mechanisms in computing equipment are turned by a-c types.

Figure 3-46 illustrates in a simplified schematic the elements of a servosystem. The functioning of such a system is described below with reference to how its principle is utilized in positioning a gun.

At a remote station, all available information about the target is collected and combined. To the gun mount is transmitted a pair of order signals telling, respectively, what values of train and elevation will put the gun in firing position. The gun has two power drive systems—one for train and one for elevation. One of these is shown in figure 3-46. Each system receives

its own order signal and performs, independently, the actions outlined below.

1. The order signal is compared with the actual position of the gun. The result of this comparison is a command (called the error signal) telling how far and in which direction the gun must move.

2. When properly amplified, the error signal operates the controls of a power drive.

3. The power drive moves the load in such a way as to reduce the error.

4. While the load is being driven, a response signal is sent back continuously and automatically for comparison with the order signal.

5. When the two error signals (train and elevation) have been reduced to zero, the gun is in the ordered position for firing.

A-C INSTRUMENT SERVOMECHANISM. Now consider how the servo principle is applied in a typical instrument servomechanism or "follow-up" using an a-c reference voltage. Compare figures 3-45 and 3-46. In figure 3-45 the parts in the mechanism corresponding to the diagram of figure 3-46 are a synchro control transformer which serves as the signal receiver and comparison device, an electronic amplifier and a-c servomotor which together correspond to the power drive, and gearing from the motor which drives the load and the synchro control transformer rotor. The amplifier may be of the tube, magnetic, or transistor type, or a combination. The load may be a dial, a computing device, a hydraulic valve, a synchro transmitter, etc. We omit a number of components used in many systems to improve the stability and response of the servo, such as damping generators, amplifier feedback and stabilizing circuits, discrimination circuits which automatically select the appropriate input signal, capacitors for improving electrical characteristics and for changing phase relationships, etc.

The input that starts the servomotor is the output voltage of the synchro control transformer. This voltage has to be amplified before it can be used. As the servomotor turns, in response to the input voltage, the rotor shaft furnishes a mechanical output to the gearing that turns the load.

The load in figure 3-45 is connected back, through gearing, to the rotor of the synchro control transformer. The result of this mechanical feedback is to drive the rotor in such a direction as to reduce the electrical output of the control transformer. When the load reaches the position originally ordered, the output of the control transformer becomes zero, and the motor stops.

The example chosen is a common type of servomechanism, but many other varieties and combinations of components are possible. It is possible to use a mechanical differential, an electrical resolver, a synchro differential transformer, a special type of movable-core transformer, or any of several other devices for the error-sensing unit. The variety possible in amplifiers has already been hinted at, as well as in auxiliary circuits and devices. Several kinds of motors are available, and so on. But the servo principle underlies all these combinations.

Now let us consider larger and more elaborate servosystems used for a gun mount, launcher, or fire control director.

AMPLIDYNE SERVOSYSTEMS

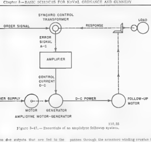
Heavy guns can be (and sometimes are) trained and elevated by direct handwheel action through the gearing system. Naturally this relatively slow and difficult method is not normally used in battle. But it is necessary for certain adjustment or maintenance operations.

For moderately light loads — such as 3-inch and smaller gun mounts and gun directors — amplidyne power drives are reliable and accurate. They are easier to maintain than the electric-hydraulic systems designed for heavier guns.

In figure 3-47 an amplidyne followup system has been reduced to its bare essentials. These are a pair of synchro control transformers (illustrated as a single unit for the sake of simplicity), an amplifier, an amplidyne motor-generator, and a followup d-c servomotor.

In the synchro control transformer the input to the stator is an order signal from a remote synchro transmitter. The position of the rotor represents the response of the load. The output of the synchro control transformer is the a-c error signal. Actually, two synchro control transformers — a coarse and a fine one — are used. When the gun is within 3° of its ordered position the fine synchro is automatically connected to control the system instead of the coarse one.

The control amplifier uses gas-filled electron tubes (called thyratrons) for two purposes. First it rectifies the a-c input; that is, it converts this input to a d-c output whose magnitude and direction measure the amount and direction of error. Second, it amplifies the signal and



110.25

Figure 3-47.—Essentials of an amplidyne followup system.

produces two d-c outputs that are fed to the control field windings in the amplidyne generator, as explained in the paragraphs following.

The amplidyne generator is a special adaptation of one type of ordinary commercial d-c generator. Such a generator has a wire-wound rotor that turns within the field of an electromagnet on the stator. The upper part of figure 3-48 shows a conventionally connected d-c field schematic. Excitation power to the field is 100 volts d-c to produce field FC. The arrow shows the direction of this field.

The larger circle between the two poles represents the rotating armature, which is driven at constant speed by a motor (not illustrated). Rotation in field FC induces an a-c voltage in the armature winding.

The inner circle in figure 3-48 represents the commutator. In the conventional d-c generator, the commutator connects the armature output to an external d-c load circuit by contact with a pair of stationary carbon brushes, 180° apart. The generated (or load) current as it passes through the armature winding creates its own magnetic field, FS. This field, called armature reaction, serves no useful purpose; indeed, it is a nuisance.

Normally, other things being equal, the power output of the generator will be proportional to the excitation power. This generator is assumed to be a 10-kw machine (10,000 watts output), and the excitation required is about 100 watts. The "amplification," therefore, is 100 to 1.

The first step in transforming this ordinary d-c generator into an amplidyne generator is to short-circuit the two brushes as shown in the second part of figure 3-48. Now an immense armature current will flow, but if excitation is cut down to about 1 watt, FC is reduced, and 100 amperes again flow through the armature, producing the same armature reaction FS as before.

The next step is to add a second pair of brushes at right angles to the short-circuited pair, and to connect the load circuit over these brushes, as shown in the third part of the figure.

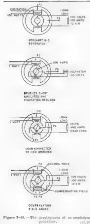


Figure 3-48.—The development of an amplidyne generator. 110.26

Now, however, the output voltage becomes very low, because the new output circuit has created its own armature reaction, FA, which opposes FC and greatly reduces its effect.

Now put a compensating winding, so connected that armature current passes through it on the second pole of the electromagnet, as in the final part of the figure. This winding produces field FB to nullify FA thereby allowing FC to become fully effective again. The ordinary d-c generator has now become a basic amplidyne generator in which full-load output is developed with 1 watt excitation ("amplification" of 10,000 to 1). Thus it can operate on very low excitation (e.g., the output of the amplifier in figure 3-47) and still furnish enough power to drive a large servomotor (the followup motor in figure 3-47).

The amplidyne generator must control the direction of its followup motor's rotation, as well as its torque. To accomplish this, the amplidyne generator has two control fields instead of the one shown in the last part of figure 3-48. One of these is wound in the opposite direction to the other. The direction of FC and of generator output depend on which receives more current from the amplifier. If the amplifier supplies equal currents to both control windings, generator output is zero and the followup motor stands still. When control winding currents differ, the followup motor will develop a torque whose direction depends on which current is greater, and whose magnitude depends on the amount of the difference.

The followup motor operates in a slave-to-master relationship with the amplidyne generator. Under a given load, its speed and direction of turning depend on the amount and direction of its d-c input from the generator. Its output is mechanical power to drive the load in the right direction until the error signal has been reduced to zero.

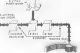
ELECTRIC-HYDRAULIC SERVOSYSTEMS

The electric-hydraulic power drive has been developed to perform heavy gun laying reliably and rapidly. Previous portions of the chapter have taken up the components of electric-hydraulic power drives. What remains to be done is to show how the several types of components work together in a unified system. These paragraphs will not go into fine details, but will limit themselves to summarizing major functions.

The order signals to an electric-hydraulic system normally originate at a remote station. They enter through a complex unit sometimes called an indicator-receiver-regulator, but more often shortened to indicator-regulator. This unit contains synchros and related devices for (1) receiving the order signal and the response, (2) computing the error signal, (3) amplifying the error signal, and (4) transmitting this signal to the hydraulic system through an arrangement of valves and pistons.

Figure 3-37 has already shown a typical gun mount electric-hydraulic power drive. The student should now be able to see how the various units—whether mechanical, hydraulic, or electric in nature—work together.

A conventional a-c electric polyphase induction power motor, connected to the ship's regular power supply, through a system of reduction gears drives the hydraulic pump (A-end) at virtually constant speed, regardless of A-end output.



110.27
Figure 3-49.—A train power drive in automatic control.

The output of the A-end is hydraulic pressure to drive the B-end. The output of the B-end is mechanical action through a shaft and pinion. The input the B-end receives from the A-end determines the direction and duration of its output. In turn, the direction and amount of motion in train or elevation depend on the output of the B-end to the gun's gearing system.

To meet varying conditions, a gun mount's electric-hydraulic system allows a choice of several methods of control. Ordinarily the responsible officer or petty officer selects the most completely mechanized method that will work. The four methods of control that may be applied to a representative medium-caliber gun mount, the 5"/38, are designated as AUTO (automatic), LOCAL, HAND, and MANUAL.

Figure 3-49 shows the sequence of operations when the mount is trained in AUTO. (The train drive is illustrated, but the same principles apply to the elevation drive.) The gun order signal from a remote source enters the indicator-regulator. There the order signal is compared with the response, and the error signal is generated and amplified. The amplified error signal positions the A-end socket ring, thus regulating A-end output. A-end output drives the B-end, which drives the training pinion and rack. Mechanical response from the gearing is an input to the indicator, where with the order signal it helps to generate the error signal. As gun position approaches synchronism with the gun order signal, the error signal decreases, becoming zero or null when gun position equals gun order.

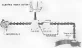
In LOCAL control the trainer's handwheels, rather than a remote source, transmit the order signal to the indicator-regulator. As before, the indicator-regulator compares the order signal with the response and transmits the error signal to the A-end. From that point on, as shown in figure 3-50, the sequence of operations is the same as in AUTO control.

In HAND control (not available in all mounts) the trainer bypasses the indicator-regulator completely. The handwheels are geared to a mechanical followup on the A-end control unit, which still receives power from the electric motor. In response to the handwheels, the A-end operates the B-end until the trainer's dial system (or, alternatively, his optical equipment) assures him that the gun is at the ordered position. Figure 3-51 shows this sequence.

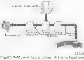
The fourth method, MANUAL control, is used chiefly to train the mount when repairs, alterations, or adjustments, are in progress. In this method the handwheels are geared directly to the training rack, bypassing the entire electric-hydraulic system.

OTHER CONTROL SYSTEMS

The foregoing examples of amplidyne and electric-hydraulic control systems have been taken from gunnery. Guns, however, are far



110.28
Figure 3-50. — A train power drive in local control.



110.29
Figure 3-51. — A train power drive in hand control.

from being the only military equipment that must be moved smoothly, rapidly, and accurately in response to incoming signals. Missile launchers and certain types of projectors have control arrangements similar, in many features, to those used with conventional guns. By their nature, systems designed to launch guided missiles must be capable of operating even more swiftly, accurately, and dependably than any except the newest gun systems. As in conventional guns, the designer's choice of amplidyne or electric-hydraulic drives is governed largely by the weight and other physical features of the given system.

Many types of lightweight equipment, both in the field of ordnance and outside it, contain electronic amplifier-rectifiers, synchros, servomotors, and simple or elaborate computing devices. Naturally this chapter cannot take up these types of equipment one by one. A reader who understands the basic mechanisms used in gun fire control, however, should have little trouble in following an instructional pamphlet that tells how similar mechanisms are designed to set a fuze, to train an antenna, or to steer a ship.

BASIC PRINCIPLES AND APPLICATIONS OF ELECTRONICS

All principles that apply to electricity also apply to electronics. Electrical principles are concerned mainly with d-c voltages and a-c voltages with frequencies of 400 hertz and below. Electronics deals with voltages of all frequencies and with devices involving the emission, behavior, and effects of electrons in vacuums, gases, and semiconductors. Technically speaking, electronics extends into many occupational fields. In ordnance some of the places where electronic principles are used are in gun, torpedo, and missile fire control systems and sonar sets. Radars use numerous electronic circuits. Although most circuits are too complex to discuss in this text, some basic electronic circuits and devices (both analog and digital) are discussed here.

ELECTRON TUBES

An electron tube is an airtight envelope in which the conduction of electrons take place. Electron tubes are classified as vacuum or gas-filled. The vacuum tube's envelope is a highly evacuated glass or metal shell, which encloses two or more elements (electrodes). The gas-filled tube contains a specific gas—usually nitrogen, neon, argon, or mercury vapor—and normally has two or three elements.

Vacuum tubes are used more widely than gas-filled tubes. There are many types of electron tubes, each of which can be made to perform many functions. Some applications are converting a-c voltage to d-c voltage (rectification), amplifying weak signals, and generating frequencies that are much higher than those that can be produced by conventional a-c generators.

Vacuum Tubes

All vacuum tubes have at least a cathode, an anode (plate), and a cathode heater (filament). In most applications, the filament is separate from the cathode, but in some cases the filament and cathode are common as shown in figure 3-52

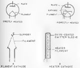


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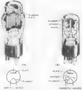
Figure 3-52.—Methods of heating the cathodes of electron tubes.



4.140
Figure 3-53.—Cutaway of 2-element tubes.

DIODE.—The simplest vacuum tube is the diode (fig. 3-53). As its name implies, it has two elements—the cathode and the plate. The filament serves only as a heater for the cathode and is not considered to be an element. One version of the diode is shown in figure 3-53A; another version is shown in figure 3-53B. The diode in figure 3-53A has a directly heated cathode, and the one in figure 3-53B has an indirectly heated cathode.

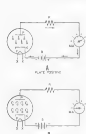
In an electronic circuit the two electrodes of a diode act in the same manner as a flow valve in a water pipe. (The British refer to the electron tube as a valve instead of a tube.)

The operation of a diode is best illustrated by connecting the plate and cathode in series with batteries and a milliammeter as shown in figure 3-54. First the cathode is brought up to normal operating temperature by applying the rated voltage across the heater terminals. If the battery is connected so that the plate is positive in respect to the cathode (fig. 3-54A), the meter will indicate current flow. If the battery is reconnected so that the plate is negative in respect to the cathode (fig. 3-54B), the meter will indicate no current flow.

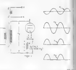
As long as the plate remains negative in respect to the cathode, no plate current will flow in the circuit, although the cathode is emitting electrons. Whether the tube is conducting or not, at a given heater temperature, the number of electrons emitted by the cathode remains constant regardless of the plate voltage (assuming that the tube is operating within its designed limits, of course). The total number of electrons attracted to the plate (thus plate current) depends on the relationship of plate voltage to cathode voltage. As plate voltage becomes more positive in respect to the cathode voltage, plate current flow increases until saturation (maximum current flow) is reached. As it becomes less positive, plate current flow decreases until the tube's cutoff (no current flow) point is reached. (Cutoff is reached when the plate voltage goes negative in respect to the cathode voltage.)

Because current can flow in only one direction through a diode its basic use is as a rectifier. If the battery in figure 3-54 is replaced with an a-c voltage source, current will flow through load resistor R only on alternate half-cycles—when the plate is positive with respect to the cathode. The rectified output is half-wave pulsating d-c voltage (fig. 3-55).

By modifying the circuit as shown in figure 3-56, full-wave rectification (and twice the average d-c voltage output) can be obtained. In this application, on one alternation V_1 conducts



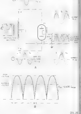
20.1
Figure 3-54. — Action of diode.



20.27
Figure 3-55. — Simple half-wave rectifier circuit and waveforms.

(passes current) up through it while V_1 is cutoff. On the next alternation V_2 conducts up through R while V_1 is cutoff. This type circuit rectifies both the negative and positive alternations of a cycle of a-c voltage.

With the addition of a filter circuit, comprising energy-storing devices (capacitors) and devices that resists changes in current (coils), either the half-wave rectifier or the full-wave rectifier may be used as a d-c power supply for various ordnance equipments. The type of power supply filter circuit used depends on the requirements of the circuit. Some equipments require smooth d-c voltage whereas others do not. Some equipments require large amounts of current, but



20.28
Figure 3-56. — Simple full-wave circuit and waveforms.

others do not. An example of a full-wave rectifier and filter is shown in figure 3-57.

Other applications of the diode are discussed in Basic Electronics, NavPers 10087 series.

TRIODE.—The triode, a 3-element electron tube, is similar in construction to the diode, except that a grid of fine mesh wire (the control grid) is added between the cathode and the plate. The space between the meshes is large enough to allow electrons to flow from cathode to plate. But the space is sufficiently small and the grid is close enough to the cathode to control effectively the flow of plate current when the proper voltage is applied between the cathode and grid.

The schematic representation and construction features of a typical triode are shown in figure 3-58. Electrical connections to the electrodes are made through wires to the base pins. The cathode sleeve surrounds the filament, and is insulated from it. The control grid is placed closer to the cathode than to the plate.

Although they have other uses, triodes are used mainly as amplifiers. Plate current in a

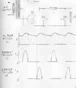


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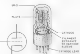
Figure 3-57.—Waveforms of current and voltage in rectifier with pi-section filter.

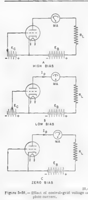


13.23

Figure 3-58.—Cutaway and schematic of a triode tube.

triode amplifier is controlled by the grid-to-cathode voltage—whether a-c or d-c. A small change in grid voltage produces a relatively large change in plate current. This grid voltage can be either the a-c signal voltage or the negative d-c voltage referred to as the bias and applied between the control grid and cathode. Figure 3-59 illustrates the effect on plate current of making the control grid voltage progressively less negative with respect to the cathode. When the negative bias is high (cutoff or above), as in figure 3-59A, no plate current flows, because the negative charge on the control grid is sufficient to repel the electron back to the cathode. As the bias is reduced (fig. 3-59B), current begins to flow, and with zero bias (fig. 3-59C) current flow is maximum. The grid may be considered an electronic control valve that regulates the flow of electrons through the tube and through the load in the plate circuit. Thus an a-c signal added to (or subtracted from) the grid bias causes the plate load current (ip)—and, therefore, the plate voltage (ep)—to vary in the same manner (fig. 3-60). This is true, of course, only as long as the input signal is small enough that it does not cause the tube to saturate or cutoff. The relatively large variations in plate current and plate voltage, which constitute the output signal, are caused by small variation in the input signal to the control grid. Thus the control grid signal is said to be amplified in the plate circuit.

In all triode amplifiers the plate voltage (and current) does not vary in the same manner as



20.4
Figure 3-59.—Effect of control-grid voltage on plate current.

the signal applied to the grid. If the applied grid signal voltage and bias voltage are negative enough to prevent plate current flow, the output voltage will not vary in the same manner as the input voltage. The same will be true if a combination of the voltages causes maximum current flow (saturation) in the plate circuit.

At high frequencies the triode is limited as an amplifier, because of certain undesirable characteristics appearing at high frequencies. This characteristic causes the a-c resistance (reactance) between the elements of the tube to decrease as the frequency increases. After the frequency has increased sufficiently to make the interelectrode reactance small or near zero, the tube is no longer useful as an amplifier. This effect is similar to connecting the elements together with wire. To overcome this undesirable effect, special multi-element electron tubes were developed for use at frequencies of 100 megahertz (MHz) and above.

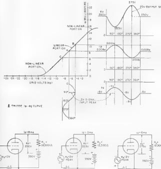
MULTI-ELEMENT TUBES.—Many desirable characteristics may be attained in electron tubes by using more than one grid. Some common types of multi-element tubes include tetrodes, which contain four electrodes, and pentodes, which contain five electrodes. Other tubes containing as many as eight electrodes are used for certain applications. Schematic representations of the tetrode and pentode are shown in figure 3-60.

Other tubes including diodes and triodes are constructed especially for high frequency operation. The tubes have very small electrodes placed close together, thus decreasing the interelectrode capacitance (which increases the reactance between the electrodes) without affecting the tube's amplifying ability. These tubes (referred to as acorn tubes) are very small physically and are not used extensively because of their limited power-handling capability.

Gas-Filled Tubes

Gas-filled tubes (gas tubes) have many uses, such as, voltage regulators, rectifiers, electronic switches and triggers, and indicators. They may have either a heated (hot) cathode or an unheated (cold) cathode. Most gas tubes are diodes or triodes and capable of handling more current than vacuum tubes of the same physical dimensions.

Gas tubes conduct when ionization occurs. (Ionization is the process by which a particle—gas in this case—loses or gains an electron thereby having a positive or negative charge. It can be produced by collisions of particles, by radiation, and by other means.) The ionization point (firing point) varies with tube construction and type of gas used.



72.10
Figure 3-50.—Triode amplification.

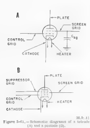


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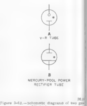
Figure 3-61.—Schematic diagrams of a tetrode (A) and a pentode (B).

After ionization has started, the action maintains itself at a voltage lower than the firing-point voltage. To maintain ionization, however, voltage must be kept above a certain minimum. If the voltage across the tube falls below this minimum, the gas deionizes and current flow stops. (The voltage at which current ceases to flow is known as the deionizing potential.) The gas-filled tube may be used as an electronic switch that closes at a certain voltage and permits current to flow and opens at a lower voltage and thus blocks the flow of current. These tubes have a very high resistance before ionization and a very low resistance after ionization.

GAS DIODES.—The cold-cathode diode requires a higher firing potential than the hot-cathode diode. The neon glow lamp or neon bulb is such a cold cathode diode. Its cathode may have the same shape as its plate so that the tube can conduct in either direction depending only on the applied potential; or the tube may be constructed to permit current flow in one direction only. The passage of current through the tube is indicated by a glow.

Glow tubes have several applications. They are used to indicate the presence of a voltage, as a source of light, as a rectifier, and as a voltage regulator. A schematic representation of a voltage-regulator glow tube is shown in figure 3-62A. The black dot denotes that the tube is gas-filled.

Hot-cathode, mercury-pool diodes (fig. 3-62B) are especially designed to serve as rectifiers. These tubes have a much higher current-handling capability than vacuum tubes. Mercury vapor is the gas used in these tubes; it is formed when the small amount of liquid mercury included in the envelope is completely vaporized by the hot cathode. These tubes are not capable of supplying their rated output until the mercury is completely vaporized. To prevent damage to the tube, sufficient time must be allowed for



20.1
Figure 3-62.—Schematic diagrams of two gas-filled tubes.

the mercury to vaporize before applying plate supply voltage to the tube.

THYRATRONS.—A gas-filled triode (fig. 3-63), or tetrode, in which a grid is used to control the firing potential is called a thyratron. The firing potential depends upon both the plate potential and the grid potential. The grid-control characteristics of a typical thyratron are shown in figure 3-64. Thus it can be seen that the firing potential increases as the grid bias increases (becomes more negative). A grid bias of -4 volts requires approximately 350 volts on the plate to cause conduction. A grid bias of -7 volts requires 700 volts on the plate to cause tube conduction—thus plate current flow. When conduction starts the grid loses control and no longer is effective as a control element. To stop plate current flow the plate voltage must be reduced to the deionizing voltage. When conduction starts, the grid loses control and a positive ion sheath is formed around the negative grid. This sheath neutralizes the negative grid, thus destroying its effectiveness as a control element.

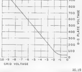
Thyratrons have many practical applications in relay and trigger circuits.

SEMICONDUCTOR DEVICES

Semiconductor devices or semiconductors (sometimes referred to as solid state devices) are being used in almost all types of military electronic equipment. Virtually all new equipments incorporate them. Many equipments use them exclusively.

In addition to replacing the electron tube in many circuits, the semiconductor has no electron-tube counterpart for many of its uses. Transistors and most other semiconductor devices are more complex than electron tubes and require a substantial amount of background knowledge to

20.18
Figure 3-63.—Thyratron.



20.19
Figure 3-64.—Grid control characteristic of a representative thyratron.

understand completely their theory and operation. Some publications (such as Basic Electronics, NavPers 10087 series, G. E. Transistor Manual, and Electronics by Chirlian and Zemanian) explain semiconductors in detail and can be obtained from BuPers or the public library.

Semiconductors Diodes

When P- and N-types of semiconductor materials are combined in manufacture, the result is a semiconductor diode. (P-type semiconductors are materials treated—doped—with an impurity to give them an overall positive charge, and N-type semiconductors are those treated to give them an overall negative charge.) If the proper bias voltage is applied, the diode will conduct heavily in one direction and very little in the other direction.

Like electron-tube diodes, semiconductor diodes serve as rectifiers, voltage regulators, and in other uses. Semiconductor diodes have additional useful application. Semiconductors vary in size ranging from small ones with current ratings of less than one milliampere (.001 ampere) to large 500-ampere rectifiers.

Semiconductor diodes are classified according to construction as the junction type or point

contact type. Both types are represented pictorially in figure 3-65. Modifications of these diodes are used for various purposes, some of which are represented in figure 3-66. Figure 3-66A is a diode (called zener) voltage-regulating circuit, figure 3-66B is a zener diode temperature compensation circuit, and figure 3-66C is a basic photodiode circuit which utilizes variations in the light impinging on the junction to produce output current variations.

Transistors

A simple transistor can be constructed by placing two semiconductor diodes back to back with the center element common to both junctions.

Transistors are made of PNP and NPN materials. The PNP transistor and the NPN transistor operates basically the same except that current flow in one is in a direction opposite to that in the other type, and bias-voltage polarities are reversed (refer to figure 3-67).

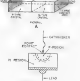


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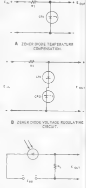
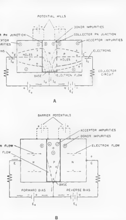
Figure 3-65. — Junction (A) and point contact (B) transistors.



20.390-.393
Figure 3-66. — Diode uses.



1.278; 279
Figure 3-67.—PNP (A) and NPN (B) junction transistors.

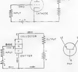
Transistors are small, yet rugged. They can withstand very high centrifugal forces. Being solid devices, they require no special envelope and no filament power. Eliminating filament power greatly increases the efficiency (compared to electron tubes). They are capable of operating at frequencies far above the operating limits of any conventional electron tube.

Transistors also operate well with low-voltage power supplies (some at a fraction of a volt), and they are capable of operating with power outputs greater than 100 watts. Finally, transistors have a very long lifetime—sometimes over a hundred thousand hours.

TETRODES.—A tetrode transistor is produced by adding a fourth element to a 3-element transistor. In the junction tetrode, the fourth electrode is essentially another base, whereas in the point-contact type, it is essentially another emitter. The tetrode transistor permits a higher frequency response and a higher power output than the 3-element transistor.

Comparing Tubes and Semiconductors

Semiconductor diodes have an emitter and a collector, corresponding respectively, to the



1.280
Figure 3-68.—Corresponding elements in triode and transistor.

cathode and plate of an electron tube diode. In transistor has a collector terminal that corresponds to the triode plate, a base terminal that corresponds to the grid, and an emitter terminal that corresponds to the triode cathode.

Figure 3-68 shows the similarities between basic circuits using the triode tube and the 3-element transistor, both NPN and PNP types. The direction of electron flow is from the cathode to the plate in the tube and from the collector to the emitter (against the arrow in the emitter terminal) in the PNP and from the emitter to the collector in the NPN.

BASIC ELECTRONIC CIRCUITS

Some basic electronic circuits are used in this section to show the principle of operation of the more complex circuits such as those found in radars, computers, and weapon power drive amplifiers. The circuits used here are simplified for instructional purposes.

Rectifier and Voltage-Regulating Circuits

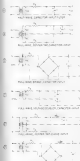
Basic rectifier circuits and voltage-regulating circuits using electron tubes were discussed earlier in this section and are not discussed further.

Basic semiconductor rectifier circuits are shown in figure 3-69. Their operation is the same as that of the electron-tube rectifier circuits. There may be a small difference in circuit construction however. The semiconductor rectifier circuit may have a small surge resistor (R) connected in series with the diode to limit the peak current.

The bridge rectifier circuit in figure 3-69D (or F) is a full-wave rectifier that with a similar input has twice the output of the full-wave, center-tapped circuit shown in figure 3-69B (if both circuits use the same input transformers).

Each rectifier has advantages and disadvantages. The half-wave rectifier is the least expensive but the hardest to regulate. The full-wave bridge rectifier is the most expensive but the most efficient rectifier.

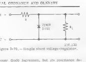
The bridge rectifier uses the entire secondary winding of its input transformer on each half-cycle of operation. On one half-cycle current flows from point 2 to 1, then in numerical sequence from 3 to 8, and then on the next half-cycle it flows in sequence from points 1 to 2, 8, 4, 5, 6, 7, 3, and back to point 1 completing the circuit.



20.408

Figure 3-69.—Basic semiconductor rectifier circuits.

A simple voltage regulator circuit employing a Zener diode is shown in figure 3-70. The Zener diode has properties that make it an excellent voltage regulator when the proper bias voltage is applied. If the voltage between points 1 and 2 increases, the current flow through the



130.130

Figure 3-70.—Simple shunt voltage-regulator.

Zener diode increases, but its resistance decreases. The voltage across the Zener and the parallel load (R_L) remains constant. The additional voltage would drop across the series resistor R.

Other voltage regulators such as those in figure 3-71A use both Zener diodes and transistors. Still others, such as that in figure 3-71B, use a regulating amplifier for improving voltage stability.

Amplifiers

Amplifiers are classified according to use, bias, frequency, response and circuit configuration. Generally, amplifiers are a combination of these classifications. An example of this would be a class A (bias), grounded-cathode (circuit configuration), audio frequency (frequency response), voltage (use) amplifier.

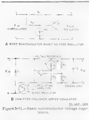
When classified according to use, amplifiers fall into two general groups — voltage amplifiers and power amplifiers. Voltage amplifiers are designed to produce a large change in output voltage, across the plate load by applying a small input voltage (signal) between the grid and cathode. The gain of a voltage amplifier is the ratio of the a-c output voltage to the a-c input voltage (voltage-out/voltage-in). Voltage amplifiers are commonly used in radars and computers.

Power amplifiers are designed to deliver a large amount of power to the load in the plate circuit of the tube or the collector (or emitter) circuit of a transistor.

They are used: (1) to drive servo motors in computers, (2) in output stages of radars, and (3) output stages of power-drive amplifiers on gun mounts and other ordnance units.

Amplifiers that are classified according to bias fall into three main classes of operation, A, B, and C.

Class A amplifiers are biased (grid-to-cathode or base-to-emitter) so that with a normal signal



20.407:.405

Figure 3-71.—Basic semiconductor voltage regulators.

input the tube or transistor will conduct during the entire grid signal cycle. As long as the amplifier operates within its limits the output will be a replica of the input. Class A amplifiers are used in audio circuits where a reproduction of the input is desired.

Unlike the class A amplifier a class B amplifier is biased so that no plate current flows in the absence of a signal to the grid or base. Plate current flows for approximately one half of each cycle (positive alternation) of grid signal voltage. Plate current is cut off for the duration of the negative alternation.

Class C amplifiers are biased beyond cutoff—about 2 to 3 times the cutoff value. This amplifier requires a large input signal to cause conduction. It conducts only for a small portion of the positive alternation of the input signal. Class C operation is used principally in radio-frequency amplifiers and is never used for audio amplification.

Amplification may be classified according to the frequency range over which they are designed to operate. These are known, as direct-current (d-c); audio-frequency (AF); intermediate-frequency (IF); radiofrequency (RF); and video-frequency amplifiers. Direct-current amplifiers are used when the signal current is in but one direction. Audiofrequency amplifiers operate in the audiofrequency range—from approximately 20 hertz to 20,000 hertz. Intermediate-frequency amplifiers and RF amplifiers operate within a particular frequency range. These amplifiers usually are tuned to a certain frequency (called midfrequency) which varies according to application. An AM radio uses 455 kHz as its IF, whereas an FM radio uses 9.1 MHz. Video amplifiers (used in radars, target designation displays, and TV) operate within a range extending from the lower audiofrequencies to about 5 MHz.

Another method of classifying amplifiers is according to circuit configuration—how the tube elements are connected in the circuit. There are three circuit configurations: grounded-cathode (or common-emitter), grounded-grid (or common-base), and grounded-plate (or common-collector).

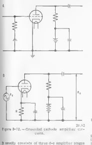
A grounded-cathode amplifier circuit is shown in figure 3-72A. The cathode may be connected to ground directly, as shown in figure 3-72A, or through a resistor (R) with a bypass capacitor, as shown in figure 3-72B. (The bypass capacitor holds the cathode at ground potential in respect to the input signal.) Common-emitter transistor amplifiers for PNP and NPN circuits are shown in figure 3-73A and 3-73B.

Grounded-grid amplifiers like the one shown in figure 3-74A are used as radiofrequency amplifiers in the lower radar frequencies and in television circuits. The signal is applied to the cathode in series with the bias voltage. The output is taken between the plate and ground. A common-base circuit is shown in figure 3-74B. Resistors R_1 and R_2 develop forward bias, making the emitter positive in respect to the base.

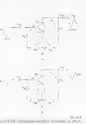
The other circuit configuration is the grounded-plate amplifier (fig. 3-75A) or the common-collector amplifier. This type circuit is used in high-frequency applications. The input signal is to the grid, and the output is taken from the cathode. Common-collector amplifiers using PNP and NPN transistors are shown in figures 3-75B and 3-75C, respectively.

Direct-current amplifiers are used extensively in some analog computers. A typical d-c amplifier circuit is shown in figure 3-76. In this circuit a fixed portion of the output (feedback) is taken from across R_2 and fed back to the base of Q_2. This provides stable gains over a wide range of frequencies.

A high-gain d-c amplifier called an operational amplifier is used in some applications



20.52
Figure 3-72.—Grounded cathode amplifier circuits.



20.413
Figure 3-73.—Common-emitter circuits; A, PNP; B, NPN.

it usually consists of three d-c amplifier stages in series (cascade), and it has a gain of up to 60,000 to 1 or higher. A typical operational amplifier circuit is illustrated in figure 3-77. Resistor R_2 is the feedback resistor.

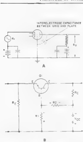
Some uses of d-c amplifiers in analog computers are: (1) to solve equations; (2) as algebraic adders in summing amplifiers; and (3) as multipliers and dividers. A schematic diagram and the equivalent circuits of the summing amplifier are shown in figure 3-78. The summing amplifier works on a similar principle as the mechanical differential, which was explained earlier in this chapter. If there are two or more voltage inputs of the same polarity, as shown in figure 3-78B, the output is the algebraic sum of the input voltages with the polarity of the output reversed (+5 and +3 = +8. By reversing the polarity, +8 becomes -8). If the polarities of the input voltages are not the same, as in figure 3-78C, the output is still the algebraic sum of the input voltages with the polarity of the output reversed (-5 and +3 = 2). (The output of a summing amplifier is opposite in polarity from the input, which means that if the input to a unity gain amplifier is +2 volts, the output will be -2 volts.)

DIGITAL DEVICES

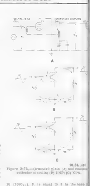
Digital computers function in the binary-numbering system using the digits 0 and 1. Their components represent data that can only be in one of two stable states — ON or OFF, conducting or not conducting, energized or deenergized. The action of a digital device or digital-computer component can best be illustrated by the action of a common light switch; it is either ON or OFF.

Binary Numbering System

A brief review of the binary numbering system may help you to better understand the digital devices that will be discussed later.



20.83;.312
Figure 3-74.—Grounded grid amplifier circuit and single supply, common-base fixed-bias circuit.



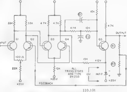
20.84.416
Figure 3-75.—Grounded plate (A) and common collector circuits; (B) PNP; (C) NPN.

The binary numbering system uses the base 2 and not the base 10; that is, it uses only two digits, 0 and 1. Thus, the sequence followed in counting up to 1000 (base 2) uses:

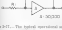
base 2		base 10	base 2		base 10
0000	=	0	0101	=	5
0001	=	1	0110	=	6
0010	=	2	0111	=	7
0011	=	3	1000	=	8
0100	=	4			

Of course you can easily see that 1000 to the base 2 (1000_2) is not equal to 1000 to the base 10 (1000_{10}). It is equal to 8 to the base 1[0]. A quick look at the number sequence shows th[at] the terms are powers of the number 2. Th[e]

decimal				binary
1	=	2^0	=	0001
2	=	2^1	=	0010
4	=	2^2	=	0100
8	=	2^3	=	1000
16	=	2^4	=	10000
32	=	2^5	=	100000



110.131
Figure 3-76.—A typical d-c amplifier.



110.132
Figure 3-77.—The typical operational amplifier circuit.

Binary addition, subtraction, division, and multiplication is accomplished in the same manner as the decimal operations. An example of addition follows:

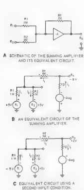
<u>Binary</u>

1 1	1	1 = carry
1101	= 13	
1001	9	
10110	22	

Boolean Algebra

Boolean algebra is used in the study of digital devices to determine the "truth value" of the combination of two or more statements. Because Boolean algebra is based upon elements having two possible stable states, it becomes very useful in representing switching circuits. This is because a switching circuit can be in only one of two possible stable states at a given time—open or closed. These two states may be represented as 0 and 1, respectively. As the binary numbering system consists of only the symbols 0 and 1, we can use these symbols with the Boolean algebra.

In Boolean algebra there are three basic operations—AND, OR, and NOT. The basic operations are represented in logical equations by the symbols shown in table 3-1. The OR operation is indicated by the addition symbol, whereas the AND operation is indicated by a multiplication symbol (the dot, parentheses, or other multiplication signs). The NOT function is indicated by a solid line over the letter or letters—example: $\overline{A}$ and $\overline{AB}$.



A SCHEMATIC OF THE SUMMING AMPLIFIER AND ITS EQUIVALENT CIRCUIT.

B AN EQUIVALENT CIRCUIT OF THE SUMMING AMPLIFIER.

C EQUIVALENT CIRCUIT USING A SECOND INPUT CONDITION.

110.133

Figure 3-78.—A. Schematic of the summing amplifier and its equivalent circuit; B. An equivalent circuit of the summing amplifier; C. Equivalent circuit using a second input condition.

Table 3-1.—Logic symbols.

OPERATION	MEANING
A · B	A and B
A + B	A or B
A	A NOT

110.134

Logic Operations

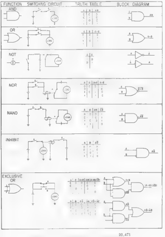
The three basic logic operations and four of the simpler combinations of the three (NOR, NAND, INHIBIT, and EXCLUSIVE OR) are shown in figure 3-79. For each operation a representative switching circuit, a truth table, and a block diagram are given. A 1 at the input indicates the presence of a signal (corresponding to the switch closed), and a 0 indicates the absence of a signal (switch open). In the outputs, a 1 indicates a signal across the load, and a 0 indicates no output.

For the AND operation every input line (two in this case) must have a signal present in order to produce an output (or all switches must be closed to produce an output). The OR circuit produces an output whenever a signal is present at any input. The NOT operation is simply an inversion, an input signal produces no output, while no signal input produces an output.

The NOR circuit operates just the opposite from the OR circuit, and the NAND operates just the opposite from the AND circuit. The EXCLUSIVE OR circuit has an output only when there are a combination of a 0 and a 1 input and not when all inputs are the same (either 0's or 1's). An EXCLUSIVE OR logic diagram is shown in figure 3-79.

Positive and Negative Logic

Logic circuits may be utilized to provide "yes" or "no" or "true" or "false" answers to specific questions. A "yes" or "true" answer is usually represented by a binary 1, and a "no" or "false" answer is usually a binary 0. As far as the circuitry is concerned, however, it is possible to use either a positive voltage or



20.471
Figure 3-79.—Logic operations, comparison chart.

negative voltage to represent either binary digit. Therefore some distinction must be made regarding the system of logic for a particular application. The term POSITIVE LOGIC is used to denote a circuit in which the voltage level representing a binary 1 is positive in respect to that used to represent a binary 0. NEGATIVE LOGIC is the term used to denote circuitry in which the voltage level representing binary 1 is negative in respect to that representing binary 0.

Basic Logic Circuits

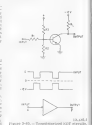
Many of the basic circuits used in digital devices are conventional electronic circuits generally applicable to electronic equipment. Circuits which perform the logic operations previously discussed, provide an output only if certain input conditions exist. They can be classified generally as gate circuits and may employ electron tubes, transistors, semiconductors, and/or magnetic cores.

The basic circuits of the inverter, OR, AND, NOR, and NAND gates are discussed briefly.

The inverter or NOT circuit is nothing more than a gate amplifier that produces an inversion of the input signal and has unity gain. The inverter circuit shown in figure 3-80 uses a PNP transistor biased at cutoff by the divider R_2 and R_3. The input signal is divided by R_1 and R_2 to make circuit gain unity. This circuit represents a negative logic circuit because the input must be negative to cause conduction. An inverter using an electron tube is shown in figure 3-81.

An OR circuit or gate with four inputs is shown in figure 3-82. Many OR circuits have only two inputs or any other practical number of inputs. The OR circuit shown has 16 possible input signal combinations ($2^4 = 16$) as illustrated in the truth table. When any one or more of the inputs receive a positive signal, the diode (or diodes) receiving that input conduct(s). This results in a positive-going output at F, measured across R_L. (This circuit uses positive logic.)

A transistorized AND gate is illustrated in figure 3-83. This version uses two inputs and positive logic. The transistors are biased so that they conduct down across R_L with no input. With either transistor conducting, there is an output across R_L. The application of positive signals at A and B at the same time, however, will cause both transistors to cease conduction and the output at F to rise to ground or zero potential representing a logic 1.



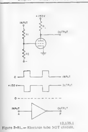
12.195.2
Figure 3-80. — Transistorized NOT circuits.

A NOR gate is a combination of an OR circuit and of an inverter. The NOR circuit in figure 3-84 uses positive logic. With no signal input (0) the NPN transistor is biased to cutoff, and the output at F is positive (1). A positive signal (1) to any of the input terminals (A, B, C, or D) will cause the transistor to conduct and the output to go negative.

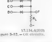
The NAND circuit combines the AND function and the NOT (inverter) function. In figure 3-85 the PNP transistors are biased for maximum conduction in the absence of signals. When positive signals are applied simultaneously to both transistor bases, both will be cut off, and the output voltage at the collectors goes relatively negative. (Note that both transistors must be cut off at the same time in order to change the output.) This is a positive-logic NAND circuit.

Flip-Flop Circuits

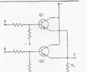
Flip-flop circuits (bistable multivibrators) are used in digital devices to supply an output



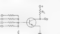
12.133.1
Figure 3-81.—Electron tube NOT circuit.



12.134.4(20B)
Figure 3-82.—OR circuits.



12.133.1(20B)
Figure 3-83.—AND circuit.

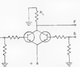


67.89
Figure 3-84.—NOR circuit.

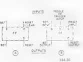
and its complement at the same time. They are used also as off-on triggers and for storage purposes in counting circuits.

Two logic symbols used to identify flip-flops (regardless of the internal circuitry) are shown in figure 3-86. The symbol in figure 3-86A has two inputs, set (S) and reset (R). The symbol in figure 3-86B has three inputs—set, reset, and trigger or toggle. The output from both are the same—set (1) and reset (0). The set input is used to get a "1" from the set output; the reset input is used to reset the flip-flop for a "1" out of the reset output. The trigger input is used to change the flip-flop from one stable state to the other. This is accomplished by applying the same signal to both transistor bases at the same time.

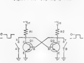
The schematic of a simple transistor flip-flop is shown in figure 3-87. Outputs are taken from points X and Y. Inputs are represented by switches A and B which temporarily ground these points when the trigger input is to be applied. The trigger input may be applied in



67.90
Figure 3-85.—NAND circuit.



124.20
Figure 3-86.—Flip-flop symbol.



20.473
Figure 3-87.—Transistor flip-flop circuit.

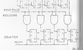
several different ways, such as by diode, transis-
tors, switches, relays, or otherwise.

In one of the two stable states of the flip-flo transistor Q_2 conducts heavily and transist Q_1 is cutoff. With this arrangement, point Y wi be at ground or zero potential, whereas point will be at the Vcc potential. As you can see, th negative potential at point X is directly connecte to the base of Q_2, keeping it forward biase and conducting heavily. If switch A is now close momentarily (simulating a SET input), the bas of Q_2 is grounded and the forward bias is re moved. This causes Q_2 to cut off and cause its collector to go negative, applying forwa bias to Q_1. Then transistor Q_1 conducts heavil maintaining the base of Q_2 at ground potentia If switch B is closed momentarily, the circu will change back to its other stable state—Q conducting and Q_1 cut off. Thus when Q_2 conduct the X output is negative or a binary 1, and Y i a binary 0; when Q_1 conducts, the Y output i 1 and X output is 0. (This circuit uses negativ logic; the voltage level that represents a binar 1 is negative in respect to the level that repre sents a binary 0.)

Flip-flops, along with other devices, are use extensively in digital computers.

Storage Register

A storage register consists of a group o flip-flops (fig. 3-88), each capable of handlin one bit (a 1 or a 0) of information. It is used



20.4
Figure 3-88.—A four-bit register and associat counter.

store a word (two or more bits of information) temporarily.

The register in figure 3-88 represents a storage register that is capable of storing a four-bit (or less) word such as 1011. The lower group of flip-flops comprises the register, and the upper group forms an associated counter. Other storage registers are designed to handle longer words, and therefore they have more flip-flops. The number of flip-flops depends on the maximum word length expected.

Storage registers together with other devices are used in digital computers to perform mathematical logic computations such as addition and subtraction.

Storage Devices

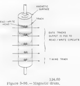
Digital equipment utilizes various storage devices. This brief discussion is limited to some common magnetic devices used for storing information over a period of time.

The on-off principle using magnetic devices is easily understood if we let the magnetized condition represent binary 1 and the nonmagnetized condition represent binary 0. In the case of magnetic cores, each core is small, and the entire core is magnetized in one direction to represent 1 and in the opposite direction to represent 0. Magnetic drums and tapes represent data as small magnetized or nonmagnetized areas on their surfaces.

A representative magnetic core is shown in figure 3-89. Its outside diameter is .050 inch; its inside diameter is 0.030 inch; its thickness is 0.015 inch. The core is magnetized by current flowing through wires that are threaded through the core. Several cores are arranged in a flat panel inside a frame to make up a matrix. A computer that uses magnetic cores for its computations contains many of these matrices.

A magnetic drum (compared to a core) provides an inexpensive method of storing large amounts of data. The amount of data the drum is able to stow, however, depends on the size of the drum. A representative drum, which may have a diameter from 5 to 24 inches, is shown in figure 3-90. The surface of the drum is divided into tracks or channels which encircle it. A number of read/write heads (at least one for each track) are used for recording and reading out information. The heads are placed a specified distance from the drum. For proper operation, this distance must be constant; therefore, the drum must be perfectly balanced. Each read/write head is connected in a separate circuit

124.54
Figure 3-89.—A magnetic core.



124.60
Figure 3-90.—Magnetic drum.

so that read or write operations can take place on any or all tracks simultaneously.

A third type of storage device is magnetic tape. It is similar to tape used with commercial tape recorders, except that a very high quality tape is required for greater accuracy. Seven-channel tape (commonly used in computers) is usually 1/2 inch wide and has a recording density of 100 to 500 binary bits per inch. This enables a 2,400 foot roll to store 3 to 16 million characters (bits of information). The main advantage of magnetic tape is its ability to store millions

of data bits inexpensively. Under ordinary operating conditions, magnetic tape is reusable many times; data on a used tape may be transferred to a new one.

Another storage device, commonly used in digital computers, is the magnetic disk. Several of these disks are used in each computer. They resemble phonograph records and are arranged in much the same way as a record stack in a modern "juke box." The main advantage of magnetic disk storage is the high storage capacity obtainable from a bank arrangement of several disks. Some magnetic disk systems can store over 5,000,000 coded digits.

PRINCIPLES OF OPTICS AND ORDNANCE OPTICAL INSTRUMENTS

The optical instruments used in naval fire control present a magnified image of the target to the observer's eye. At the same time, the observer sees an image of a reticle, or reference mark, located inside the instrument itself. By accurately superimposing the reticle image on the target image, the observer can establish an accurate line of sight to the target. The rangefinder, by establishing two separate lines of sight, makes it possible to find the target range by a form of triangulation.

To form the reticle and target images, an optical instrument must control the path of the light that passes through it. It does so by the use of lenses, prisms, or mirrors, or some combination of these elements. This section briefly reviews the behavior of light as it passes through optical elements. Familiarity with these basic principles will make possible a general understanding of most optical instruments.

NATURE OF LIGHT

Light is a form of energy. It travels from one point to another in the form of waves. Except for their wavelengths and frequency, light waves are identical with other types of electromagnetic radiation, such as radio waves and gamma rays. The wavelength of visible light ranges from approximately 0.35 micron to 0.70 micron. (A micron is one thousandth of a millimeter.) The color of light depends on its wavelength. In order of increasing wavelength, the colors are violet, indigo, blue, green, yellow, orange, and red. Radiation of longer wavelength than visible red is called infrared, or heat radiation. Beyond infrared are the radio waves. Radiations shorter than visible violet are (in the order of decreasing wavelength): ultraviolet, X-rays, gamma rays, and cosmic rays.

If a small object is dropped into water, a series of concentric circular waves will spread out from the point of impact. This provides a familiar analogy for the behavior of light waves. Waves in water, however, move on a two-dimensional surface; light waves move in three dimensions. The waves that move outward from a small source of light may be thought of as a series of concentric, rapidly expanding spheres.

In the study of optics it is convenient to trace the path of light rays, rather than waves. At any given point, a light ray is an imaginary line used to show the direction in which the light wave is moving. Since the wave is an expanding sphere, its direction of movement at any point is along a radius of that sphere. A ray, then, is a radius of the sphere formed by the wave front, and is at right angles to the wave front.

A telescope or similar instrument will receive only a small part of the light emitted by the source. Each wave that enters the instrument, therefore, is only a small part of a sphere. If a wave comes from a nearby source, the part of it that enters the instrument will be strongly curved. And the rays (radii of the spherical wave) that enter the instrument will be diverging. But if the source is at a great distance, the part of the wave that enters the instrument will be nearly flat; for all practical purposes it can be considered a plane. Since the rays are perpendicular to the wave front, the rays that enter an optical instrument from a distant point can be considered parallel. Figure 3-91 should make this clear.

In the drawings in this section only a few rays are used to represent the light that enters the instrument. But remember that light rays enter an optical instrument at every point on its first lens. In diagrams of optical instruments, only a few of these rays will be shown. Three rays are usually enough to show the path of light and formation of images within the instrument.

Light travels at about 186,000 miles per second in air. In a denser medium, it moves more slowly. For example, the velocity of light in water is about 140,000 miles per second; in glass it ranges from 95,000 to 127,000 miles per second, depending on the optical density of the glass. This difference in velocity makes it possible for an optical instrument to control the path of light, to form images, and to magnify them.

12,230
Figure 3-91.—Light rays from nearby and distant sources.

REFLECTION

When light traveling in air strikes the surface of a mirror, most of it is reflected back into the air (fig. 3-92). The incoming ray is the incident ray. The normal is an imaginary straight line, at right angles to the mirror surface, passing through the point of incidence. The angle of incidence is the angle between the incident ray and the normal, and the angle of reflection is the angle between the normal and the reflected ray. The law of reflection states, first, that the angle of incidence is equal to the angle of reflection; and, second, that the incident ray, the reflected ray, and the normal all lie in the same plane.

When light traveling in air strikes the surface of clear glass, a part of the light will be reflected; the rest will enter the glass. If the incident ray lies on the normal (zero angle of incidence), about 5% of the light will be reflected. As the angle of incidence is increased, the amount of reflection increases. As the angle of incidence approaches 90°, the reflection approaches 100%.

When light traveling in glass strikes an air surface, part of the light will be reflected back into the glass; the rest will enter the air. At zero angle of incidence, about 5% of the light

110.30
Figure 3-92.—Reflection at a mirror surface.

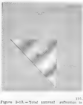
will be reflected back into the glass. As the angle of incidence is increased, the amount of reflection increases rapidly. When the angle of incidence becomes greater than the critical angle, all of the light will be reflected back into the glass; none of it will enter the air. (The critical angle for various types of glass, at an air surface, varies from 37° to 43°.) This property of a glass-air surface, called total internal reflection, is used in many optical instruments. Figure 3-93 shows how the line of sight may be deviated through an angle of 90° by internal reflection at the diagonal face of a right-angle prism.

If the prism in figure 3-93 is rotated (in the plane of the page) through any angle, the angle of incidence will be changed by the same angle. The angle between the incident ray and the reflected ray will therefore be changed by twice that amount.

REFRACTION

When light passes from air into glass, its speed will decrease. It will resume its original speed when it leaves the glass and enters the air. If a ray of light strikes an air-glass or a glass-air surface at an oblique angle, its change of speed will result in a change of direction. Figure 3-94 shows why this is so.

The diagonal lines in the figure represent the approaching light waves. Since they are coming from a distant source, they are parallel. As each wave enters the glass, various points along the wave front will slow up successively, and as a result the entire wave front will change its angle. Since the direction of movement, shown by the



110.31
Figure 3-93.—Total internal reflection in a prism.

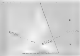
ray, is at right angle to the wave fronts, the light bends as it enters the glass. The opposite effect occurs when the waves leave the glass. Now the various points along the wave successively increase their speed. As a result, the emergent waves are parallel to those that entered the glass. And the emergent ray is parallel to the incident ray, although it has been displaced on one side.

Figure 3-95 illustrates some of the terms used to describe the refraction, or bending, of light. The LAW of refraction states that light bends toward the normal when it passes into a denser medium; it bends away from the normal when it passes into a less dense medium. The exact angle of bending may be easily calculated. It depends on the angle of incidence, and on the optical density of the two media. Optical density is expressed as index of refraction. (The index of refraction of a vacuum is 1; the index of refraction of air is approximately 1. The various types of optical glass range from approximately 1.5 to 1.96.)

When the two glass surfaces are parallel, as in figure 3-94, the emergent ray is parallel to the incident ray. When such elements occur in optical instruments (as, for example, in the end windows of rangefinders), they do not deviate the line of sight. However, if the two glass surfaces are not parallel, the line of sight will be deviated, as in figure 3-96. Thus prisms are used

12.232
Figure 3-94.—Path of wave fronts through a sheet of glass.

12.2[illegible]
Figure 3-95.—Terms used to describe the refraction of light.



116.32
Figure 3-96.—Refraction in a prism.

12.234
Figure 3-98.—Deviation of rays passing through a convergent lens.

in rangefinders to deviate the line of sight through a small angle.

IMAGE FORMATION

Figure 3-97 shows the path of parallel rays of light on passing through two prisms mounted base to base. Each ray will be deviated toward the base of the prism it passes through. The upper rays deviate downward, and the lower rays upward. All the rays emerging from the upper prism are parallel, and all the rays emerging from the lower prism are parallel. But if the surfaces of the two prisms in figure 3-97 are rounded off to form a convergent lens, as in figure 3-98, each ray will have a different angle of incidence, and will therefore bend to a different degree. The ray that passes through the center of the lens is normal to both surfaces, and does not bend. Such a ray is said to lie on the optical axis of the lens. The greater the distance from the axis, the greater the angle of incidence at each surface, and the greater the deviation toward the axis. If the lens is perfect, all rays parallel to the axis will meet at a single point, called the focal point of the lens.

116.33
Figure 3-97.—Deviation of rays in two prisms.

Every lens has two focal points, one on each side. The two focal points are equally distant from the lens. The distance from either focal point to the center of the lens is the focal distance or focal length of the lens.

Figure 3-99 shows three rays of light diverging from a point source and passing through a convergent lens. (An infinite number of rays strikes the lens, but three suffice to show what happens.) All the rays from A that pass through the lens coverage and meet at point B. Point B is therefore the image of A. Note that B is itself a source of light, since rays diverge from it just as they do from A. If a sheet of paper is held at B, the image may be seen as a bright point on the paper. If B lies between the lens and the observer's eye, the image may be inspected directly.

In figure 3-99 the distance from point A to the lens is greater than the focal length. If the source were at or closer than the focal point, the rays emerging from the lens would not converge.

A target or other object is visible when it reflects light toward the observer. For each point on the target, a convergent lens will form

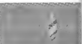
110.34
Figure 3-99. — Image of a point.

a corresponding image point behind the lens. These image points together form a real image of the whole target which would appear inverted on a flat sheet of paper held at this location (see figure 3-100).

VIRTUAL IMAGES

Figure 3-101 shows the path of several rays diverging from the point of an arrow when the arrow lies between the lens and its first focal point. The lens makes the rays less divergent, but does not bring them to a focus. However, an observer on the right side of the lens may see the point (and the rest of the arrow) by looking through the lens. Since the observer is accustomed to assuming that light travels in straight lines, it will appear to him that the rays from the arrow are actually coming from P, and he

110.35
Figure 3-100. — Formation of a real image by convergent lens.



110.36
Figure 3-101. — Formation of a virtual image by a convergent lens.

sees an image of the arrow apparently located at P. However, if a sheet of paper is held at P, no image will be formed on the paper. The arrow image at P is therefore not a real image. No rays actually diverge from the arrow at P, as they do from a real image; they merely appear to. The arrow at point P is said to be a virtual image.

Note the following characteristics of the virtual image formed by a convergent lens:

1. It is erect. (The real image formed by such a lens is inverted.)
2. It appears to be farther behind the lens than the light source.
3. It is enlarged.

A single convergent lens may be used as a simple magnifying glass by holding it close to the eye. The object distance is adjusted until the image appears in sharp focus when the muscles of the eye are completely relaxed. The object distance will then be equal to the focal length of the lens, and the virtual image will lie at infinity.

ELEMENTARY TELESCOPES

A telescope provides, to an observer's eye, an enlarged image of a distant object. A single lens cannot be used to provide an enlarged image of a distant object. However, a telescope can be made by using a combination of two or more lenses. The first lens, called the objective, forms a real image of the distant object. The observer may examine the real image through a second lens, called the ocular or eyepiece lens.

The ocular serves as a simple magnifying glass. It forms an enlarged virtual image of the real image formed by the objective.

Figure 3-102 shows the path of rays from a distant target through a simple telescope. The drawing shows two rays from the head of the arrow converged by the objective to meet at point B. A real, inverted image of the target lies in a vertical plane through B. After crossing at B, the two rays diverge and strike the ocular lens, which makes these rays less divergent. To the observer's eye, the two rays appear to diverge from point C. The virtual image of the target therefore lies in a vertical plane through C. (The ocular is usually adjusted so that this image is at infinity; the drawing shows the image at C only for convenience.) To the observer, the virtual image appears to be considerably larger than the object itself. The telescope therefore forms an enlarged image of the distant object.

In some instruments, the ocular is so mounted that the observer may adjust its distance from the objective to focus on the real image of a close target. In the sight telescope, this focusing adjustment is unnecessary, since the target is always at a considerable distance.

The real image formed by the objective lens and the enlarged virtual image seen by the observer are inverted. To function as a useful fire control instrument, the telescope must present an erect image. One way to do this is to add an erector lens, used as a second objective with the first real image as its target. The erector forms a real image of the first real image and inverts it a second time. The ocular then forms an enlarged, erect, virtual image of the second real image.

A few telescopes, and most binoculars, use prisms to erect the image, by internal reflection at the various prism faces. Figure 3-103 shows typical ways in which prisms may be used to erect an image.

To provide a fixed line of sight through a telescope, a reticle may be added. The reticle is a flat piece of glass on one surface of which suitable reference marks, often two lines (called crosshairs or crosswires), intersecting at a right angle, have been engraved.

In practice, it takes more than four optical elements (objective lens, erector lens, ocular lens, reticle) to make a sight telescope. Additional lenses are necessary to correct the aberrations or distortions of the optical system. Or an individual lens may be constructed of several carefully cemented pieces of glass. In a "simple" telescope, the objective may consist of two or three separate lenses, cemented together. The erector and ocular are each made up of from two to four separate lenses. The spacing of the various elements must be maintained precisely; moisture must be excluded, and the interior parts and cementing compounds must be protected against tampering, and corrosion and other causes of deterioration. All Navy optical equipment is therefore hermetically sealed. Fixed equipment such as gun and director sight telescopes, rangefinders, etc., is in addition charged with dry helium or nitrogen gas.

SIGHTS

The primary purpose of any sight on a gun or director is to establish a line of sight from the observer to the target. When the target is distant, the sight may in addition provide an enlarged image of the target to improve the accuracy of the line of sight. In the type of telescope described above, this can be done by using the reticle crosshairs to establish the line

110.37
Figure 3-102.—Simple telescope.

110.38
Figure 3-103.—Prism erecting systems.

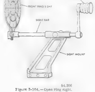
of sight, while the remainder of the optical system enlarges the target image.

Chapter 6 will explain the geometry of the fire control problem and the function of the optical sight and the line of sight in it. Here let us concentrate on the optical systems used in sights. No specific marks and mods of sight are described here, but we can identify three general types of sight:

1. Simple sights without optical systems.
2. Telescopic sights with fixed optical components.
3. Sights with movable optical components.

SIMPLE SIGHTS WITHOUT OPTICAL SYSTEMS. An example of this is the peep sight used on infantry small-arms weapons, or the ring sight (figure 3-104) installed for emergency use on some antiaircraft gun mounts. The observer looks through the eyepiece. When he has the target in line with the center of the front sight, the line of sight to target is parallel with the gun bore. To provide for ballistic and other fire control corrections, the observer must offset the line of sight so that it diverges from the gun bore by a certain angle. He can judge the amount of offset in this simple sight by using the concentric rings and spokes of the sight instead of the sight's center to align the line of sight to target. Use of this type of sight is restricted to targets at short ranges in emergencies when other methods are not available. Effective use of the sight to direct gunfire requires considerable training, and at best it is not as accurate as other systems.

TELESCOPIC SIGHTS WITH FIXED OPTICAL COMPONENTS. Sights of this type are used in antiaircraft rapid-fire gun mounts, in fire control directors, and in heavy turret mounts. Two typical systems are diagrammed in figure 3-105. The main difference between them is that one has all the elements in a straight line, while the other uses prisms. In the direct system (part A in the figure), the objective lens forms an inverted real image of the target. This image falls on the engraved surface of the crossline lens, or reticle. Between the reticle and the erecting lenses are three color filters and a plain glass filter, so mounted that the operator can bring any one of them into the line of sight. A filter will, under some conditions, increase the contrast of the target image, and decrease glare from sky and water. The erecting lenses erect the target image, and form a real image



54.206
Figure 3-104. — Open ring sight.

110.39
Figure 3-105.—Optical systems of telescopic sights with fixed optical components. A, Direct (no prisms); B, Indirect (prismatic).

near the eyepiece of the crosslines superimposed on the target. The sealing window, of plain glass, helps to keep out dirt and moisture. The eyepiece may be moved to focus the image without affecting the seal of the rest of the instrument.

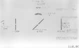
The indirect optical system, shown in part B of figure 3-105, is basically similar. The principal difference is that the line of sight is twice reflected by prisms, so that most of the telescope lies at right angles to the line of sight from gun to target. Two separate objective lenses, or two lenses cemented together, form the first real image. Other varieties of this kind of optical system may use a single prism. To adjust the offset to the gun bore, the telescope is moved as a whole.

SIGHTS WITH MOVABLE OPTICAL COMPONENTS. There are two main varieties of sight with movable optical components.

In one, which is used in heavy antiaircraft gun mounts, the optical system in principle resembles that illustrated in part B of figure 3-104, except that an additional prism as well as the objective or head prism are linked mechanically to a sight setting system on the gun mount. Thus the line of sight can be offset without moving the entire telescope. (Such a system may additionally contain erecting and other prisms.)

In the other variety of sight with movable optical components, shown in figure 3-106, the optical system includes a reflecting glass, a collimating lens, and a lamp. This kind of optical system is used with gyroscopic lead-computing sights (explained in a later chapter). The two windows seal the instrument to keep out dust and moisture. The system illustrated here does not magnify the target image. The operator observes the target directly, through the two windows and the clear reflecting glass. The lamp illuminates the reticle, which is located at the focal point of the collimating lens. Rays of light from the reticle are therefore parallel after they pass through the lens and are reflected toward the operator by the reflecting glass. Because these rays are parallel, the reticle image appears to lie at infinity, and the reticle will not change its apparent direction when the operator moves his head from side to side. The sight's gyroscopic mechanism rotates the reflecting glass so that it will deflect the reticle image as seen by the operator. The operator then trains and elevates the gun mount to keep the reticle on target; this automatically offsets the gun bore as required by the computed solution to the fire control problem.

In another variant of this principle, the reticle image is transmitted through the reflecting glass, while the target image is reflected. The principle remains the same, except that it is the target image rather than the reticle image that is apparently shifted. It is also possible to use two mirrors, one for elevation and one for train, combined with a true



110.40
Figure 3-106.—Optical system for a lead-computing sight. Simplified.

telescopic optical system, filters, and an additional device called a "pellicle" (actually a kind of half-mirror) which can reflect a radar scope image to the operator. This arrangement makes it possible to use the sight even when (as in fog or darkness) no optical target image is available.

RANGEFINDERS

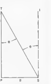
As you will find in chapter 6, one important item of information needed for solving the fire control problem is the range to the target. One way of getting this information is to use an optical rangefinder. Let's briefly discuss the principle of operation of the most used type — the stereoscopic rangefinder. (Another type, not taken up here, is the coincidence rangefinder, which is similar in external appearance, somewhat different in optical principle, and not as versatile.)

The rangefinder consists essentially of a system of optical units assembled in a long, cylindrical tube, mounted in a turret or director, so that only the protruding ends are exposed. On its forward surface, the tube has a window at each end. Through these windows, the operator establishes two separate lines of sight to the target. The distance between the windows is the base length.

The rangefinder determines range by solving a right triangle in which one side (the base length) and two angles are known. Range is one of the unknown sides. In figure 3-107, TPS is the range triangle. PS is the known base length (B) of the rangefinder. The target lies at T; PT is the target range (R). TPS is always a right angle; the line of sight from the left end window is at a right angle to the rangefinder tube axis. The two lines of sight converge and meet at the target, forming angle of convergence θ. SI is an imaginary line parallel to range line PT. Angle TSI is therefore equal to angle of convergence θ. The rangefinder measures the angle of convergence by measuring angle TSI.

Because this is a right triangle, it is apparent that $R = B \cot \theta$. The equation may be solved for R, then, as soon as the angle of convergence has been measured.

A pair of human eyes uses several clues in its perception of relative distance. Of these, the one on which the functioning of the stereoscopic rangefinder depends is convergence, i.e., the sensing of angle θ (fig. 3-108) by the muscular effort required for both eyes to see a single



110.41
Figure 3-107. — The range triangle.

fused image. You can demonstrate this to yourself in exaggerated fashion by first holding your finger a foot in front of your nose, and focusing on it; then, without shifting your line of vision, focusing on an object ten feet or more distant.

The "base length" (or pupil-to-pupil distance) of a pair of human eyes is about 2.5 inches. Beyond a range of about 450 yards or so the lines of sight of the two eyes converge so little that changes in angle θ are too small to sense. If the base length could be increased, θ could be reliably measured for much longer ranges. In one sense, as shown in figure 3-108, that is what the rangefinder is designed to do.

55.289
Figure 3-108. — Function of the rangefinder.

Figure 3-109, shows in simplified schematic form the optical system of a stereoscopic rangefinder. (Each of the two telescopes contains an erector system, which has been omitted from the drawing for the sake of simplicity.) The diamonds represent the reticle pattern; the arrows represent the two images of the target. Because the apparent angle of convergence of the two reticles is fixed, the reticle pattern appears to be at a certain fixed distance in space. If the target happens to be at this distance, target and reticle will appear to be equally distant from the observer. If the target's convergence angle differs from the reticle's, the right-hand line of sight to target must be adjusted till they match. To do this, the knob on the right is used to rotate two compensator wedges—thin prisms with sides nearly parallel—through which the light from the target passes. But since they are not parallel, rotating the prisms will deflect the line of sight. This corresponds to changing angle θ (fig. 3-106).

Figure 3-110 shows the image as seen in the stereoscopic rangefinder eyepieces. This represents two images (one for each eyepiece) blended stereoscopically to form a single impression. If the rangefinder operator turns his range knob until the target appears to be at the same range as the large central diamond, the range scale will read the actual range to the target. The other reticle markings (wander marks or ranging marks) are used in estimating how far from the target projectiles are bursting or falling, and in correcting fire accordingly.

ELEMENTS OF SOUND

Sound is the physical cause of your sensation of hearing. Anything that you hear is a sound. But there are also sounds that you cannot hear.

Sound travels in the form of waves. These waves vary in length. A long wave length is heard as a low-pitched sound, a short wave length is heard as a high-pitched sound. A complete wave length is called a hertz. If the sound is below about 20 hertz (abbreviated Hz) or above 15,000 hertz, most people cannot hear it. The range between, which can be heard, is called the audible range and the sounds you hear are known as sonics. Sounds below this range—below 20 hertz—are subsonics. Sounds above this range—above 15,000 hertz—are ultrasonics.

In order to have sound, it is necessary to have a sound source which can vibrate, and a medium to transmit the vibrations. And, for our purposes, it is necessary also to have a detector.

Anything which moves rapidly to and fro, or vibrates and thus disturbs the medium around it, may become a sound source. Bells, radio loudspeaker diaphragms, the human voice, and musical instruments are familiar sound sources.

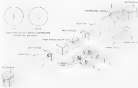
Sound waves are passed along by the particles of the material through which they travel. Therefore, a material substance, a medium, is necessary to transmit sound waves. A sound medium is any material substance through which sound energy will travel. It may be a gas (such as air), a liquid (water), or a solid (steel). The medium must be something material, or the sound will not be transmitted. Sound will not travel through a vacuum. Most of the time you are mainly concerned with sounds transmitted through air, but in sonar, you are interested in the liquid medium—water.

Commonly, the detector of sound is the human ear. It receives part of the sound wave energy from the medium, and converts it into an impulse that goes to the brain. Electrical devices like microphones or other transducers can also respond to sound waves and convert them into electrical impulses. (In general, a transducer is any device that converts electrical signals to some other form, or vice versa.) These impulses may be reproduced again as sounds or in some other way—for example, as spots on a cathode-ray tube. Although the human ear can detect as sound only vibrations in the audible range, microphones can be made to detect sounds of any wavelength.

CHARACTERISTICS OF WAVES

TRANSVERSE WAVES. If you throw a stone into a quiet pool, series of circular waves will travel away from the disturbance. Figure 3-111 shows such waves diagrammed as though seen in cross section. The water waves are a succession of crests and troughs. Water waves are known as transverse waves because the motion of the water molecules is up and down, at right angle to the direction in which waves are traveling. A cork on the water bobs up and down as the waves pass by.

Although sound waves are not transverse waves, transverse waves (fig. 3-111) like the ripples on a water surface illustrate clearly the notions of amplitude and cycle. Before you threw the stone into the water, the water level (if perfectly undisturbed) was just halfway between the crest and the trough of each wave. The maximum displacement of the surface from this "zero level" is the amplitude of the wave motion. A



120.42
Figure 3-20. — Elementary stereoscopic rangefinder.

55,294
Figure 3-110.—Reticles and target as seen in stereoscopic rangefinder eyepiece.

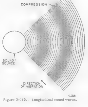
71.19
Figure 3-111.—Transverse water wave.

cycle is one complete double vibration—in this case measured from one crest through zero, the trough, zero again, and the next crest. If you take zero as your reference or starting point, you must include one trough and one crest. If you measure the number of cycles that pass a fixed point in one second, you have the frequency in hertz.

LONGITUDINAL WAVES. Sound waves are longitudinal or compression waves, set up by some vibrating object such as a sonar transducer. In its forward movement, the vibrating transducer pushes the water particles lying against it, and thus produces an area of compression or high pressure. The backward movement of the transducer produces an area of low pressure, or a rarefaction. This action goes on and on, and sets up a spreading series of compressions and rarefactions. In figure 3-112 the compressions are represented by dark rings. As the sound waves spread out, their energy at the same time is spread through an increasingly large area, and the wave motion at a distance is weaker (i.e., amplitude decreases).

The wavelength is the distance from one point along the wave to the next point of similar compression. The particles of the medium vibrate longitudinally—that is, parallel to the direction in which the sound is propagated.

You already know that the frequency of the wave is the number of cycles per second. In the motion of the sound wave through the medium, the particles of the medium move back and



4.221
Figure 3-112.—Longitudinal sound waves.

forth in a limited space, passing the wave along, as it were.

Sound waves can go through all gases, liquids, and solids, but not through a vacuum, because there are no particles in a vacuum to be subjected to alternate compression and rarefaction. In different substances and at different temperatures and pressures sound travels at different speeds. In air, the velocity (speed) of sound is about 1,090 feet per second at 32°F. at sea level. For each 1° rise in Fahrenheit temperature, the velocity is increased by 1.1 feet per second. For instance, in air of 72°F., sound travels at the rate of 1,090 + (72 − 32) x 1.1, or 1,090 + 44 = 1,134 feet per second.

In pure water, the velocity of sound is approximately 4,708 feet per second. In sea water, the velocity depends on salt content (salinity), pressure, and temperature. Sound travels at a speed of about 4,800 feet per second in sea water at 39°F.

WAVELENGTH

If a sonar transducer vibrates at the rate of 25,000 vibrations per second, and if the temperature is 39°F., the first wave will be 4,800 feet away at the end of the first second. Between the transducer and this wave there will be 25,000 other compressions. Thus the wavelength, that is the distance between points of similar compression, must be 4,800 ÷ 25,000, or 0.149 foot, because there are 25,000 compressions extending through a distance of 4,800 feet. The wavelength always can be found if the frequency and the velocity are known, according to the following relationship: $W = \frac{v}{f}$, where W is wavelength, f is frequency, v is velocity.

Example: Suppose that the wavelength is 0.4 foot and the frequency is 12,000 hertz.

What is the velocity?

$$0.4 = \frac{v}{12{,}000}\text{; or,}$$

$$v = 0.4 \times 12{,}000 = 4{,}800 \text{ feet per second.}$$

Similarly, if the wavelength and the velocity are known, the frequency can be found.

$$0.4 = \frac{4{,}800}{f}\text{; or,}$$

$$f = 4{,}800 \div 0.4 = 12{,}000 \text{ hertz.}$$

CHARACTERISTICS OF SOUND

As already indicated, the human ear detects vibrations in the audible range as sounds. Concentrate for a moment on what you hear as you read this. No matter how quiet a place you are in, you will hear something. Many of the sounds will have some kind of pattern or organization — for example, speech, music, Morse code, automobile horns, police or fire sirens, ship's whistles, humming motors, etc. These either have patterns that can be interpreted by your mind into specific feelings or thoughts (e.g. speech or Morse code or music), or at least have identifiable pitches or rhythms. Other sounds may be quite without pattern, though not necessarily meaningless — for example, rushing water, radio static, applause, rustling leaves. Such disorganized or patternless sound is, in contrast to "organized" sounds, called "noise." (However, the term "noise" in connection with the problems of communications and signal detection is used in quite a different sense, as will be explained later.)

A musical note has a pattern of regular vibrations. Such a sound has three characteristics — pitch, intensity, and quality.

An object that vibrates at high frequency produces a sound with a high pitch, as, for instance, a police whistle. The slower vibration of a ship's whistle causes a low-pitched sound. When the frequency is low, the sound waves are long; when it is high, the waves are short. Velocity is not affected by pitch.

Intensity (roughly equivalent to loudness) at any selected frequency varies with amplitude. Wavelength and amplitude are independent variables.

Now consider sound quality. As we defined it above, a noise has no identifiable dominating frequency or pitch. It is composed of a large number of frequencies sounding simultaneously. But all sounds of identifiable pitch that you normally hear can be analyzed into more than one frequency. In a note sounded by a musical instrument, the lowest (and principal) frequency is the fundamental, and other, higher, frequencies (called harmonics or partials) present in the sound give the sound much of its characteristic color or quality. Quality depends in large degree on just what frequencies are present, and in what proportion. Hence the difference between the sounds produced by a trumpet and a violin both playing the same sustained note. Other factors also affect quality, such as how the sound begins, how it ends, and how it fluctuates in pitch

and intensity while sounding. Such considerations make sounds recognizable even when the pitch cannot be identified. Niagara would sound different from a leaky bathroom faucet even with its sound intensity reduced to comparable level. Ability to recognize differences in sound quality is an extremely important characteristic in sonar and hydrophone work.

SOUND TRANSMISSION IN WATER

As you may have inferred by this time, one of the main reasons for including this section on sound is its importance in the sonar method of submarine detection and location. This is done either by detecting sounds made by submarines in the water, or by radiating sound pulses into the water and analyzing the echoes that return to identify those from submarines. Details concerning sonar gear appear in chapter 13. In this article we discuss briefly the characteristics of sound transmission through water.

When sonar's sound pulse travels through the water, and when the echo returns, they encounter hazards which reduce their strength. Signal strength lost in this manner is known as transmission loss.

ABSORPTION. Some of the sound is absorbed in passing through the water. The amount lost this way depends on the state of the sea. Absorption is high when the winds are great enough to produce white caps and cause a concentration of bubbles in the surface layer of the water. Absorption is also great in wakes and strong currents, such as rip tides. Absorption is greater at high frequencies than at low.

SCATTERING. Sound waves are weakened when they traverse sea water that contains seaweed, silt, animal life, air bubbles, etc., which scatter the sound beam. Scattering reduces echo strength, especially at long range.

REFLECTION AND REVERBERATION. Sonar sound pulses behave somewhat like light in that they can be reflected and refracted. The target can reflect a sound pulse, but so can other underwater objects, and so can the sea bottom and the sea surface ("total reflection" much like that of light in glass, as described in an earlier section of this chapter). The combined echoes from such disturbances are called reverberations. Since they are reflected from various ranges, they seem to be a continuous sound which is stronger at first and gradually fades away. Reverberations from nearby points may be so loud that they interfere with the returning echo from a target.

REFRACTION. Refraction can distort the path of the sound pulse in the water. Sound speed varies with medium density, and this can cause bending of a "ray" of sound much as it bends a ray of light. This effect is described in further detail in chapter 13.

SOUND PERCEPTION

It is no news that when some one is talking to you in a noisy room it is more difficult to hear him than when the room is quiet. To make himself understood, the speaker may turn his face directly toward you, or move closer to you, or talk louder, or eliminate or tone down the source of noise. So far as your own sensing of his voice is concerned, all of these boil down to one thing: He is increasing the strength of his signal relative to that of the disturbing noise, or increasing the signal-to-noise ratio.

In communication work and in sound detection you will find that this ratio is extremely important. The ratio is expressed in decibels (abbreviated db). Ten decibels make a bel, a large unit named after the inventor of the telephone, Alexander Graham Bell. A decibel is a logarithmic expression of the difference in level or intensity between a "reference" signal and another signal, or between a signal and noise or interference. The intensity level of signal A is n decibels higher than that of reference signal B if

$$n = 10 \log A/B$$

Under laboratory conditions (i.e., completely quiet room, with no sound-reflecting surfaces, use of "pure" tones—fundamentals with no harmonics—of constant pitch in the most sensitive range of the human ear, etc.) 1 decibel is the minimum difference in sound level that the average observer can detect. As a practical matter, under fairly quiet (not laboratory) conditions, an attentive, acute observer cannot detect differences in level of such sounds as speech and music much less than 3 db—and a signal 3 db higher in intensity than a second signal has twice the sound energy of the second sound.

When an audible signal is equal in level to the noise or interference accompanying it, and is of similar characteristics to the interference or noise as regards frequency, pulse rate (if any),

etc., the human ear cannot distinguish it from the noise. (In this sense, "noise" can include not only unorganized sounds that we previously defined as noise, but also other unwanted signals such as speech, even though such signals are not noise in the sense of an earlier definition. From this point of view, noise is any sound that interferes with reception of the desired signal.) Sometimes, if the noise is in a different frequency range from the desired signal, comes from a different direction, or is different in some other fundamental characteristic, it may be possible to filter it out to some degree mechanically, electrically, or by "selective listening." Thus, you may be able to communicate on the phone through a loud high-pitched squeal or low-pitched hum, but it's much harder to do this if there's another lively conversation on the wire at the same time.

In general, however, there must be a sizable difference in level between signal and noise for effective reception. In this connection, "sizable difference in level" doesn't mean a 50% difference, or even a 100% difference. You simply cannot perceive satisfactorily a signal that is only twice as loud as the accompanying noise (i.e., a signal at 3 db level). Bear in mind that in a quiet room ordinary speech is about 60 db higher in level than barely audible background noise, and this represents a signal-to-noise ratio of about one million to one. Under excellent radio conditions, the signal may be 30 db above the interference ("static") level; this signal-to-noise ratio is about 1,000 to one. When the signal-to-noise ratio in sonar reception is 10:1 (i.e., 10 db), only a well-trained Sonarman with excellent hearing can reliably get the signal above the interference. A Sonarman with less training won't get the signal unless it's at a level of 15 db. The lowest level signal that any Sonarman has ever been able to perceive is on the order of 5 db (three times as loud as the interference).

These ratios apply also to radio communication. The signal-to-noise ratio concept (and even measurement in db) has been applied even to video (visual) signal presentation and in general to other areas in which power levels must be compared, or intelligible signal reception through "noise" (audible, visible, or electrical) must be measured.

The human ear's sensitivity differs throughout its frequency range, and this characteristic is utilized in sonar to provide for optimum performance. Although sonar pulses and echoes are often in the ultrasonic part of the sound frequency spectrum, sonar equipment converts the received signal to a selected frequency, usually in the range of 600 to 1,000 Hz, where the human ear is at its best with respect to sensitivity, pitch discrimination, and ability to recognize an echo by its characteristic quality.

CHAPTER 4

EXPLOSIVES AND AMMUNITION

This chapter is designed to introduce to the student the principles of those naval weapons that depend for their functioning on the use of chemical explosives and propellants. These include gun projectiles, torpedo and rocket warheads, and explosive trains in mines, and bombs.

The next section of this chapter discusses the characteristics and nomenclature of chemical explosives in general. (Since much of the second volume of this text is devoted to nuclear weapons, such weapons and the principles of nuclear reactions are not discussed here.) The section following that discusses gun projectiles and weapons other than guns.

As the preceding chapter brought out, many words that have precise technical meanings when used in specific fields of science and technology have much broader, and sometimes quite different, meanings when they appear in more general contexts. This is worth repeating here because in this chapter and throughout the remainder of this text you will continually encounter words of this kind, such as range, booster, explosive, and detonate.

Note also that there have been some relatively recent changes in nomenclature and definitions in the subject matter of this chapter. Since these changes have probably not yet been incorporated into all the older technical materials you will encounter on the subject, the older usages are indicated where appropriate, for your convenience. However, make it a habit to avoid using older terminology and colloquialisms; restrict yourself to the up-to-date vocabulary of the naval officer's profession when discussing technical matters of this kind.

EXPLOSIVES AND RELATED MATERIALS

Broadly, if used without further qualification, the term explosive includes all those substances that, when initiated (by spark, friction, shock, or other means), undergo a rapid chemical reaction that results in the formation of gases and the release of a great amount of stored energy. The reaction is accompanied by high pressure and usually by high heat. In this sense the term explosive is broad enough to include all the substances described in this section.

Note that this usage of the term, though broad, excludes as explosive substances such things as high-pressure steam which may burst (or colloquially, "explode") a boiler, or high-pressure gas that under certain circumstances may rupture its container.

In strictly technical usage, however, the term explosive includes only those substances that detonate. This means that when their reaction is initiated they produce a sharp shock wave that releases all the stored energy almost instantaneously. As it appears hereafter in this text, the term explosive will be used in this strict sense only (when applied to chemical explosives).

High explosives are classified by use into three broad groups: (1) primary (initiating) explosives, (2) Auxiliary (booster) explosives, and (3) bursting charges. Primary explosives are the most sensitive of high explosives and are used to detonate other charges. They are particularly sensitive to shock, heat, or other physical disturbances and are therefore used in initiating devices (such as fuzes, described later in this chapter) to set off chemical reactions in less highly sensitive substances. Boosters are used to detonate explosive charges when the initiating explosion is not sufficient to cause a thorough (high-order) detonation of the main charge. Bursting charges are comparatively insensitive to heat, they are the explosive payload of the projectile (or warhead), detonated by the initiators or boosters. Burster charges damage the target by blast, heat, or fragments from the container (such as, projectile body, bomb case, etc.),

Propelling charges or propellants are explosive-like substances that burn rather than detonate. The rate of burning, though rapid compared with the burning of common combustible materials, is much slower than detonation. (For example, a high explosive like TNT detonates at the rate of several thousand yards per second; a typical gun propellant burns at a rate measured in inches per second.) An important characteristic of any propellant's burning rate is that under a given set of conditions it will always be the same. Propellant burning rate is controllable, and, in contrast to explosives which detonate rather than burn, can be predetermined within close limits by adjusting the propellant's composition, the conditions of burning, and related factors.

Note that the distinction between explosives and propellants rests as much on the conditions under which they react as upon differences in composition. Explosives that normally detonate can be made to burn, under certain conditions not characteristic of their usual application; conversely, under abnormal conditions, propellants can be made to detonate. To underline this point, consider gasoline vapor mixed with air. Under optimum conditions in an internal combustion engine cylinder, this mixture burns like a propellant to produce useful thrust. Under less favorable conditions it detonates with damaging impact, evidenced by a characteristic "knock" or "ping."

Propellants may be liquids or solids (but such fuels as gasoline are not propellants in the sense defined in this article). When a propellant burns, it produces hot high-pressure gas. In such applications as rockets and JATO units the thrust produced by the gas as it escapes through a suitably shaped nozzle is used to drive a load (i.e., the rocket head or aircraft). In such applications as mortars, guns, and depth-charge projectors the thrust produced by the gas directly propels the projectile.

With specific reference to propellants used in guns, the term cool propellant is used to describe one that burns at a relatively low temperature. This is an advantageous characteristic.

For reasons which will become evident later in this text when explosive ordnance is described, practically all explosive and propellent units contain two or more explosives and explosive devices, arranged so that they function in sequence when the unit explodes. This series of stages is called an explosive or propellent train (fig. 4-1).

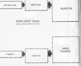


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Figure 4-1.—Explosive and propellent trains. Simplified schematic.

In explosive devices like bombs and gun projectiles, the explosive train typically consists of an initiating device called a detonator, containing a relatively small quantity of primary explosive; a booster which contains a larger quantity of less sensitive explosive and is set off by the functioning of the detonator; the booster detonates the burster, which is the main charge of the device and in general is much less sensitive than the preceding stages. In specific devices there are variations on this basic sequence of stages; in small gun projectiles the explosive train is simpler, with the booster omitted or combined with the initiating device, while large aircraft bombs and mines have additional auxiliary stages.

Propelling charges use similar trains. The initiating stage is called a primer, and produces a hot flame which sets off the next stage, called the igniter. The igniter in turn sets off the main charge.

PYROTECHNICS are chemical devices that produce light for illumination or signaling, or smoke for signaling, and may utilize explosive or propellent substances in performing their functions. Specific pyrotechnic devices used by the Navy are described later in this chapter.

CHEMICAL AGENTS include a variety of gaseous, liquid, or solid substances used for

signaling, for screening, for harassing or attacking the enemy by asphyxiation or other chemical damage to personnel, or for burning enemy targets. The three main groups of chemical agents are war gases, smokes, and incendiaries. Further detail on specific chemical warfare devices and substances appears later in this chapter.

DEMOLITION AGENTS are explosives issued and used in specialized demolition equipment other than ammunition. Certain military explosives like TNT are used both in ammunition and in demolition equipment, but in general the requirements of an explosive for demolition and for use in ammunition are not the same, and many explosives, such as Explosive D and nitrostarch respectively, are used either in ammunition, or in demolition equipment, but not in both. The Navy uses demolition explosives in such work as destruction of obstacles or hazards to navigation (such as the sinking of floating hulks), blasting preparatory to construction, destruction of classified equipment if capture by the enemy is imminent, or destruction of designated enemy targets by specially trained personnel such as frogmen.

OUTMODED TERMS. Older textbooks on ordnance, and even current texts directed to supply personnel and activities, use the expression low explosive to include the various explosive-like substances whose reaction is a burning process rather than a detonation. The term is no longer correct in military context. It is retained in shipping instructions and similar documents because the law still recognizes it as a valid blanket term covering propellants and pyrotechnics.

BASIC CHEMISTRY OF EXPLOSIVES AND PROPELLANTS

Explosive substances include a large number of chemical compounds and mixtures. Relatively few of these have the characteristics that make them practical for military use, and the discussion in this chapter applies only to those actually used in the Navy.

Most explosives and propellants used by the Navy are organic compounds or mixtures of explosive organic compounds, most of them based on nitrogen. (Hence the presence of "nitro" in the chemical names of most Navy explosives.) A few are inorganic compounds (the chief example is lead azide, used as the sensitive initiator in detonators). One explosive used in the Navy is a simple mechanical mixture (not a chemical compound) of chemicals which individually are not explosives — this is black powder.

It is important to note the distinction between mixtures and chemical compounds. A mixture consists of two or more distinct substances, either chemical elements or chemical compounds, which may be mixed in various proportions as described. The components in a mixture (of solids) can always be identified individually, even though a microscope may be necessary to do it; no matter how fine the components may be ground and how thoroughly they may be conglomerated, the mixture cannot be truly homogeneous. In a chemical compound, on the other hand, (1) the substance (if pure) is always homogeneous down to the point where it is broken up into its constituent chemical elements; (2) the components, when isolated, are invariably chemical elements; and (3) the constituents are always present in exactly the same proportions.

Broadly, two kinds of chemical reactions account for the functioning of both propellants and explosives. One is combustion — the combination of oxygen with other atoms or atomic groups with the accompanying release of energy. The other is a molecular breakdown or disintegration (followed by some recombination) of the relatively unstable nitrogen compounds that, as mentioned above, make up most Navy explosives and propellants.

In propellants, much of the energy developed by the reaction characteristically comes from oxidation. No significant proportion of the oxygen comes from the atmosphere. In black powder, the oxygen comes from potassium or sodium nitrate, which yields oxygen when heated; the oxygen combines with the other two components of the mixture (charcoal and sulfur). In other propellants, the oxygen is part of the original composition, and recombines with other elements when the composition breaks up.

In high explosives, oxidation is not so important a feature of the reaction, though it is usually present. The important energy source is in the breakup of the chemical bonds of the original composition and the recombination of the elements into simpler compounds.

The products of detonation and burning (in explosives and propellants respectively) include the usual products of complete combustion (e.g., carbon dioxide, water vapor), products of incomplete combustion (e.g., carbon monoxide, free hydrogen), products of molecular breakdown and partial recombination (e.g., free nitrogen, oxides of nitrogen, methane, hydrogen cyanide),

and unburned residues of the original composition. Some of these products are harmless, some are suffocating, some are combustible or even explosive, and some are dangerous poisons even in fairly low concentrations. These are dangerous substances, particularly in enclosed spaces (where, for example, a high-explosive-loaded projectile may have burst). They are also dangerous in enclosed gun mounts, which are therefore fitted with gas-expelling devices to eliminate them. When such gases are not promptly expelled they may ignite while the gun is being reloaded, causing a burst of flame inside the mount called a flareback.

CHARACTERISTICS OF EXPLOSIVE AND PROPELLENT REACTIONS

• VELOCITY. An explosive reaction differs from propellent reaction in its velocity. The velocity of combustion of explosives and propellants may vary within rather wide limits, depending upon the type of substance and upon its physical state. The burning rate of colloidal cellulose nitrate powders used as propellants in modern guns is in the order of 24 centimeters per second and up at average gun pressures. The velocity of reaction of high explosives ranges from about 2,000 to 8,500 meters per second.

• HEAT. An explosive reaction is always accompanied by the rapid liberation of heat. The amount of heat represents the energy of the explosive and hence its potentiality for doing work. The quantity of heat given off by an explosive or propellent reaction is not as large as is popularly supposed. A pound of coal, for example, yields five times as much heat as a pound of nitroglycerine. However, coal cannot be used as an explosive, because it fails to liberate heat with sufficient rapidity, and because it does not incorporate an oxidizing agent.

• GASES. The main material products (as distinct from energy products) of explosive or propellent reactions are hot gases and a small amount of solid residue. The pressure characteristics of the gases evolved are discussed below; their composition was discussed in the preceding article. In gun barrels, propellent gases have an additional erosive effect, which contributes significantly to the wear of the gun bore. The effects of such wear on gun performance are taken up in further detail later, in chapter 5.

• PRESSURE AND SHOCK WAVE. The high pressure accompanying a propellent or explosive reaction is due to the formation of gases which are expanded by the heat liberated in the reaction. The work which the reaction is capable of performing depends upon the volume of the gases and the amount of heat liberated. The maximum pressure developed and the way in which the energy of the explosion is applied depend further upon the velocity of the reaction. When the reaction proceeds at a low velocity, the gases receive heat while being evolved, and the maximum pressure is attained comparatively late in the reaction. If, in the explosion of another substance, the same volume of gas is produced and the same amount of heat is liberated, but at a greater velocity, the maximum pressure will be reached sooner and will be quantitatively greater. However, disregarding heat losses, the work done will be equal.

The rapidity with which an explosive develops its maximum pressure determines its brisance. A brisant explosive is one in which the maximum pressure is attained so rapidly that its shock wave shatters material surrounding it.

INITIATION OF EXPLOSIVE AND PROPELLENT REACTIONS

Explosive and propellent reactions are initiated by the application of some stimulus which provides energy required to get the reaction started. In general, propellent substances are commonly initiated by heat. The resulting reaction is a burning process, which occurs on the exposed surfaces of the substance and progresses through the mass as each layer is consumed. However, some high explosives will react when sufficient heat is applied, especially if heat is applied suddenly throughout the mass. Initiation by percussion (direct blow), or by friction, is a form of initiation by heat derived from the energy of the blow or friction.

High explosives, such as the main charges of mines or torpedoes, in general require the sudden application of a strong shock or detonation to initiate the explosive reaction. This detonation is usually obtained by exploding a smaller charge of a more sensitive high explosive in contact with or close to the main charge.

Detonation of an explosive mass can also be transmitted to other high explosives in the vicinity, without actual contact. The explosion resulting is said to be initiated by influence,

and is called a sympathetic explosion. When this happens with mines or depth charges that are located too close together in the water, the phenomenon is called countermining.

The amount of energy necessary to initiate the reaction is the measure of the sensitivity of the explosive or propellant. Sensitivity is important in selecting an explosive for a particular purpose. For example, the explosive in an armor-piercing projectile must be relatively insensitive or the shock of impact will detonate it before penetration. Too much sensitivity is also undesirable because minor shocks or temperature variations incident to normal handling would initiate the reaction.

Sensitivity has little relation to the power developed by a given weight of explosive. TNT, for example, is quite insensitive, but is pound for pound a much more powerful explosive than mercury fulminate, an initiating compound of great sensitivity.

CLASSIFICATION OF NAVY EXPLOSIVE AND PROPELLANTS BY USE

In the remainder of this section, the characteristics of individual chemical explosives and propellants now in use in the Navy will be described. These are arranged in the following classification based in each case on their principal use:

1. PROPELLANTS. Propellants are used to propel projectiles from guns, to propel rockets, launch torpedoes, and catapult aircraft. Examples are smokeless powder, ballistite, Cordite, and black powder. Figure 4-2 shows smokeless powder grains of various sizes.

2. PRIMARY (INITIATING) EXPLOSIVES. The initiation of an explosive reaction requires the application of energy in some form. Propellants are commonly ignited by the application of flame, while explosives are set off by a severe shock. Many primary explosives can be used for initiating either propellants or explosives because they produce both a flame and a shock when exploded.

A PRIMER is used to initiate the burning of a propellent explosive. A simple primer consists of a small amount of lead azide and a small charge of black powder. When fired, the primer produces the flame required to ignite the next component in the train.

53.144
Figure 4-2. — Smokeless powder grains (caliber .30 to 16"/50); the two white grains are SPCG powder.

A DETONATOR is used to initiate the reaction of a high (disrupting) explosive. It may consist of a charge of lead azide or lead styphnate, either alone or with granular TNT or tetryl in a container. When fired, the detonator produces the shock necessary to initiate the explosive reaction.

3. AUXILIARY EXPLOSIVES. Large propellent charges and relatively insensitive high explosives require an intermediate charge, so that the increased flame or shock will ensure reaction of the main explosive charge. This auxiliary, when used with propellants, is called an ignition charge. It consists of a quantity of flame-producing black powder. The auxiliary explosive used with high explosives is called a booster. It consists of a quantity of more sensitive high explosive, such as tetryl or granular TNT.

4. BURSTERS. Explosives of this classification are all employed to create damage to the target under attack. They are used alone or as part of the explosive charge in mines, bombs, and torpedo warheads, and in projectiles as a

burster charge. There is a wide variety in this category, but the more common examples are RDX, TNT, and tetryl.

Propellants

The primary function of a propellant is to produce gases under pressure which can be used to develop a propulsive thrust. This gas pressure must be controlled to avoid exceeding the strength of the container in which it is produced (e.g., guns and torpedo tubes).

Any explosive would serve for propellant purposes if the velocity of explosion could be controlled. Investigations of this problem led to the development of today's smokeless powder. Nitrated cotton (pyrocotton), the main constituent of smokeless powder, is itself a high explosive entirely unsuitable as a propellant. It is combined with an ether-alcohol mixture to control its burning rate.

Smokeless powders are now used almost universally for propellant charges. For military purposes (especially for weapons larger than small arms) there are three main classes: (1) single-base, (2) double-base, and (3) multi- or triple-base powders.

In single-base powders, cellulose nitrates (nitro-cellulose) form the only explosive ingredient. Other materials in single-base powders are included for suitable form, desired burning characteristics, and stability.

Double- or multi-base powders include nitroglycerin to assist in dissolving the nitrocellulose during manufacture, as well as to add to the explosive qualities. Single-base nitrocellulose powders have lower burning temperatures and cause less wear in the gun bore than double-base powders. Present multi-base powders, with a large proportion of the "cool"-burning explosive nitroguanidine, produce maximum temperatures comparable to those of single-base powders.

Propellants for present-day U.S. Navy guns larger than small arms are composed either of single-base or multi-base powder. Double-base powders are used as rocket propellants.

Single-Base Smokeless Powder

This type of powder is used by the U.S. Navy as a propellant in guns 20-mm and larger. It is a uniform ether-alcohol colloid of purified nitrocellulose, plus a small amount of diphenylamine as a stabilizer to retard deterioration of the powder. The grains are cylinders about four to five times as long as their diameters. Larger grains burn more slowly and are used in larger calibers. Figure 4-2 shows the range of sizes. Small grains have 1 longitudinal hole; larger grains have 7. The number and size of holes determines the burning area of the grain (in addition to its ends and convex surfaces) and therefore its burning rate; these have been carefully calculated for each caliber. The grains have a hard, smooth finish, and have much the same texture as horn. Newly manufactured grains are generally translucent and amber. As the powder ages it darkens to opaque dark brown, then black. These changes do not, however, indicate any loss of stability.

Smokeless powder deteriorates in two ways, and particularly in the presence of moisture. First, it decomposes slowly in storage because it is not entirely stable chemically, and eventually will burn spontaneously if decomposition is allowed to run its course. The decomposition products include nitrogen oxides which tend to form acids, thus facilitating further decomposition. Diphenylamine is slightly alkaline in effect, and neutralizes the acid products. This doesn't prevent further decomposition, but prevents the process from accelerating. Short of the extreme of spontaneous combustion, this chemical deterioration does not make the powder dangerous to use. Its principal effect is to weaken the powder slightly, since some of the decomposition that should have taken place in the gun has taken place slowly in the magazine, and the powder therefore cannot produce as much heat energy.

The second type of deterioration is loss of volatile components (ether and alcohol). These tend to evaporate if the powder is in the open. A loss of volatiles increases the burning speed of the powder; severe increase in burning speed will cause the powder to develop excessive pressures in the gun when it is fired. Thus loss of volatiles can make the powder ballistically dangerous.

Smokeless Powder Designations

Letter designations for some of the single-base smokeless powder (SP) used with Navy guns are as follows:

1. SPD—smokeless powder that consists of colloided nitrocellulose and diphenylamine (the stabilizer). This powder is commonly known as PYRO powder by the U.S. Navy and has been used in standard service ammunition.

2. SPDN—smokeless powder composed of nitrocellulose and dinitrotoluene, to which is

added other ingredients to control the potential of the powder and to aid in plasticization. This composition also contains diphenylamine, which acts as the stabilizer.

3. SPDF—a modification of the basic composition of either SPD or SPDN made by adding a coolant or flash inhibitor, generally potassium sulfate. This combination of materials results in a flashless charge for the gun in which the powder is designed for use.

4. SPDE—smokeless powder containing lead carbonate for de-coppering purposes; otherwise it is similar to SPD powder.

5. SPC—a recently perfected cool-burning powder of special nitrated nitrocellulose containing centralite as a stabilizer.

6. SPCF—a powder similar to SPC powder, but containing ingredients that render the powder flashless.

7. NACO—a unique cool-burning propellent of the SPC type. This powder was developed in the latter part of 1950, and it was proofed and accepted by the Navy a few years later. NACO (Navy cool) gun powder burns at a temperature 300 degrees cooler than standard gun powder. Consequently the barrel life of rapid-fire guns is more than doubled. Another important characteristic of NACO powder is the elimination of most of the muzzle blast and smoke usually associated with gunfire. The virtual absence of smoke provide the Navy, for the first time, with a universal propellent suitable for round-the-clock operations. To prevent detection, firing ships will no longer have to employ two kinds of powder—a smokeless type for daytime and a flashless type for nighttime use. NACO serves both purposes, eliminating many handling and storage problems.

NACO propellent is now being produced for 3"/38, 5"/54, and 8"/55 guns.

Multi-base Powder

Multi-base powder is used in many calibers of guns. It is commonly called Cordite N or SPCG and is composed of four principal ingredients—nitrocellulose (19 percent), nitroglycerine (a little under 19 percent), nitroguanidine (55 percent), and a stabilizer called carbamite or ethyl centralite (a little over 7 percent). Of these 4, the first 3 are explosives. A small amount of potassium sulfate may be added as a flash inhibitor. In some calibers other minor ingredients may be added.

Multi-base powder grains resemble pyro powder grains in size and shape. They have smooth, chalk-white surfaces. After considerable time in storage, the surface color may tend to yellow, but this is not a sign of deterioration.

Multi-base powders are far more stable in storage than equivalent pyro powder, because of relatively low nitrocellulose content, small content of volatiles, and low hygroscopicity. They are more suitable as gun propellants than double-base powder (described below); gases produced by a multi-base powder with nitroguanidine are much less erosive than those of double-base powder. Multi-base powders also are cheap to produce, have little residue after burning, and are relatively insensitive to high temperatures in stowage.

Storing Gun Propellants

In storage, smokeless powder must be protected against high temperatures, and sealed to prevent entrance of moisture and loss of volatiles. To protect against high temperatures, all magazines in which ammunition containing smokeless powder is stored must be adequately insulated and ventilated, and if necessary refrigerated. Moreover, recording or maximum-minimum thermometers are installed and read daily to verify that the ammunition is uniformly maintained at the lowest practicable temperatures. To protect against entrance of moisture and to prevent excessive loss of volatiles, ammunition containing smokeless powder is kept in sealed tanks or equivalent sealed containers. The tanks are not expendable; they must be periodically inspected and repaired if necessary. They must not be opened when loaded except for inspection or if the ammunition is to be used.

Solid Rocket Propellants

The stream of hot gases that propels a rocket is produced by chemical reactions; the fuel may be either solid or liquid. In this chapter we are concerned only with propellants used in ballistic rockets (i.e., those that do not incorporate systems for guidance after launching). Propellants used only in guided or ballistic missile propulsion are described in Principles of Guided Missiles and Nuclear Weapons, NavPers 10784 series.

Solid rocket propellants are double-base compositions with added ingredients for plasticizing, control of burning rate, and reduction of flash,

Gas pressure during burning is about one-tenth of that in a gun barrel, and erosion effect is not important in this application.

A typical propellant grain is made up of a composition identified as Type N-2 (JPN). Its main ingredients are nitrocellulose (slightly over 51 percent) and nitroglycerine (a little less than 43 percent). It also contains two plasticizers for homogeneity of composition, stabilizer (ethyl centralite), potassium sulfate to reduce flash, are carbon black to control burning rate. Depending on the particular rocket motor in which it is to be used, a grain is an extrusion of either cruciform (cross-shaped) or hollow cylindrical cross section, machined in a special lathe to the dimensions required for mounting. Single extruded rocket propellant grains range up to 60 inches in length and 6 inches in diameter. Larger grains for other applications may be cast rather than extruded.

From 1 to 4 grains of ballistite propellant are used as the propelling charge in a rocket motor. The grains are designed to burn at a uniform rate to provide uniform thrust during burning. In cruciform grains with suitable plastic inhibitor strips, the burning area, and hence the rate of gas production and thrust, tend to remain constant throughout the burn time. In hollow cylindrical grains, plastic inhibitors bonded to the grain limit burning area during the first part of the burn period. Cylindrical grains have holes at regular intervals to equalize pressures inside and surrounding the cylinder.

Like gun propelling charges, rockets must be stowed under conditions favorable to storage. Normally, rocket motors are stowed in different magazines from the heads with which they are used. Like pyro powder, double-base propellants such as ballistite must be protected from excessive heat and from moisture. Rocket motor magazines are ventilated, cooled, and inspected daily just like smokeless powder magazines. Rocket propellants are not subjected to surveillance or oven tests aboard ship. A shelf-life date is stencilled on the motor, if required. If the motors have short-circuiting tabs on the leads to the firing squib, these must be left on the rocket until the rocket is to be fired.

On many rocket motor tubes is printed the critical temperature above which the rocket should not be fired. Nor should a rocket motor be used if parts are missing, if the propellant grain is fractured, or if it is loose in the motor tube.

High Explosives

A high explosive for use in bursters must ideally have the following qualities:

1. Low sensitivity to shock of handling, gunfire, and impact against armor.
2. Maximum power.
3. Good fragmentation characteristics (i.e., ability to break up its container into lethal fragments upon detonation).
4. Low cost for manufacture, handling, and loading.
5. Maximum stability for good durability and resistance to adverse conditions like moisture, heat, etc.

No single explosive meets all these requirements suitably for all applications, so the Navy uses a number of explosives. The important ones which will be studied here are TNT, HDX, HBX, tetryl, and Explosive D. Explosives used only for demolitions will not be discussed. Of the five explosives named, the first four often are used in varying forms or with other substances intermixed.

TNT (trinitrotoluene), the best known of military explosives, is made by treating the organic compound toluene with nitric acid. At temperatures below about 170°F, TNT is a crystalline substance (white when pure, but yellow to brown as found in munitions), chemically quite stable (it won't react with metals or become unstable even in temperatures approaching 150°F.), and quite insensitive to shock. However, excess moisture makes it hard to detonate; it should be kept dry. It is loaded by casting—pouring the molten substance into a cavity in the projectile or explosive device. Its detonation rate is about 7,000 meters per second. After prolonged storage, cast TNT may give off an oily exudate that is not itself oversensitive but combines with cellulose material such as wood or natural fabric to make an easily combustible and sometimes even explosive compound. This exudate on the exterior of a projectile or other explosive device is a real fire or explosive hazard. It must be wiped off promptly (but without using soap or other alkaline compounds, and without using steel scrapers).

Cast TNT can be used as a bursting charge in gun projectiles (other than armor-piercing), torpedo, rocket, and missile warheads, and mines. In granulated form it is more sensitive and can be used as an auxiliary explosive (booster). TNT is also the main component of two other

explosives—amatol and tritonal. Amatol, used mostly in very large aircraft bombs, is a mixture of TNT with ammonium nitrate—the mixture is cheaper than straight TNT. Tritonal is a mixture of TNT and aluminum powder. Though the aluminum does not significantly affect the powder of the explosive, it increases brisance.

RDX, also known as "Cyclonite" and "Hexogen," is made by nitration of a complex organic compound, and is substantially more powerful and more sensitive than TNT or Explosive D (which is described below). When pure, coating RDX crystals with wax makes it insensitive enough to handle, but its pure crystalline form is nonetheless too sensitive for use as a military explosive. To make it usable, other materials must be added. RDX is available in the following forms:

1. Composition A. A mixture of RDX and 9 percent wax. Since this composition is as insensitive as Explosive D but is more powerful, it is used as a projectile filler in place of Explosove D.

2. Composition B. A mixture of about 60 percent RDX, 40 percent TNT, and less than 1 percent wax, it is used as a projectile and bomb filler.

3. Composition C. A plastic mixture of about 90 percent RDX and 10 percent emulsifying oil, used as a demolition explosive.

HBX. There are in service use two varieties of HBX: HBX-1 and HBX-3. HBX-1 is a cast explosive, consisting of a mixture of RDX, TNT, aluminum powder, and a desensitizer (chiefly wax). Stable, relatively insensitive to impact, and more powerful than TNT, it is used as a rocket head burster. HBX-3 has a much larger proportion of aluminum powder to increase brisance, and produce much greater destructive effect underwater. It is used in some underwater explosive devices.

Tetryl is produced by nitration of an aniline-based organic compound, and is both more powerful and more shock-sensitive than TNT. It is used as a burster in small gun projectiles (40-mm and 3"), but is more generally employed as an auxiliary or, when mixed with a primary explosive, in detonators.

Explosive D. This noncommittal appellation continues to reflect the aura of secrecy that once surrounded this explosive, in the closing years of the last century. What made it the subject of cloak-and-dagger concealment was its then revolutionary combination of high power (nearly that of TNT) with sensitivity so low that an armor-piercing projectile containing an Explosive D burster can be fired through armor plate without being detonated. It is a phenolic compound in crystalline powder form, chemically stable up to 150°F. when not exposed to unprotected metal. (Burster cavities in armor-piercing projectiles are protected by varnish before Explosive D is loaded.)

Primary (Initiating) Explosives

The first chemical reaction in the train or series of stages which culminates in the detonation of an explosive burster or the burning of a propellant occurs in the primary explosive. The primary explosive is the most sensitive in the train, and is present in the smallest quantity. (Detonation of a "blockbuster" bomb with thousands of pounds of high explosive burster begins with the miniature explosion of a few grams of initiator.) The primary explosive may be set off by the impact of a small firing pin, by the heat produced by the passage of a firing current through a platinum filament, or by some other appropriate stimulus. To ignite a propellant, the primary element in the train (the primer) must produce a hot flame of sufficient temperature, size, and duration for reliable action. To detonate a high explosive, the primary element in the train (the detonator) must produce a shock sufficient to detonate the succeeding elements. The primary explosives most often used in naval ammunition today are lead azide, lead styphnate, DDNP, tetracene, and nitromannite. (Mercury fulminate, once the leading primary explosive, has now been superseded because of its disadvantages.)

Detonators and primers differ chiefly in auxiliary ingredients. Thus, oxidizing agents such as nitrates or chlorates are added to increase shock effect and sensitivity; abrasives like ground or powdered glass increase sensitivity to firing pin action; fuels such as antimony trisulfide increase flame energy. Explosive binders like nitrocellulose or nitrostarch are used to provide structure for the primary mixture and to hold it in place, and graphite or other electrical conductors are used to increase conductivity for electrical initiation.

Auxiliary Explosives

Auxiliary explosives are the middlemen of the explosive or propellent train. They function as "amplifiers" to transmit the relatively feeble

explosive shock or the intense but ephemeral flame produced by the primary element, increase it, and get the main charge of insensitive explosive to detonate or the propellant to start burning.

In explosive trains, the auxiliary explosive element is generally called a booster. For detonating large masses of bursting charge (as in some aircraft bombs and mines), more than one booster may be used. Auxiliary explosives widely used in munitions include purified granulated TNT (which is more sensitive than cast TNT), tetryl, and black powder.

Black powder is the principal auxiliary explosive in propellant trains. It is the oldest of explosives; its use in guns dates back to the 12th century. It is a mechanical mixture (not a compound) consisting mainly of saltpeter (sodium nitrate) with lesser proportions of charcoal and sulfur. The exact ratios of the components vary, depending on the application. It comes in varying grain sizes, which are used as indicated:

1. Large grains.—Impulse charges.
2. Granular.—Ignition charges for propellants and for saluting charges.
3. Fine-grain.—Primer charges; expelling charge in illuminating projectiles.
4. Meal.—Pyrotechnics and fuzes.

Except for application No. 1 above (which, as later chapters in this text will mention, is rapidly becoming obsolete), black powder is no longer used as a propellant. When it was so used in guns, it fouled the bore with unburned residue, made large quantities of irritating and easily visible black smoke, produced a brilliant flash when fired, caused excessive erosion, and even with scientifically shaped grains to retard burning rate, it burned much too fast for efficient use of the energy developed.

Black powder is considered the most dangerous explosive handled aboard a man-of-war. Although it possesses practically unlimited chemical stability if stored in airtight containers, it deteriorates irregularly when exposed to moisture, which it absorbs readily. Black powder is not affected by moderately high temperatures, nor is it subject to spontaneous combustion at ordinary storage temperatures. It is, however, highly combustible, very sensitive to friction, shock, sparks, or flame, and extremely quick and violent in its action when ignited. Black-powder dust is exceedingly dangerous, and its accumulation during the handling of any black powder should be prevented.

PYROTECHNICS

Pyrotechnics is based on the Greek name for fireworks. The Navy uses pyrotechnics not for celebration but for illumination, and signaling. A pyrotechnic charge is a mixture of chemicals (generally oxidizing agents and combustibles) which reacts to produce light or smoke. Other chemicals may be added to the mixture to color the light or smoke. Some pyrotechnic devices have small quantities of explosive or propellant materials to project the pyrotechnic components in a desired direction, or to scatter them.

The Navy utilizes a large variety of pyrotechnics, but only a few common examples, all used on surface vessels, can be taken up here.

Illumination Device

The illuminating projectile (colloquially called a "star shell") is a bright-burning flare that is conveyed to the desired location by firing it in a projectile body from a gun. A timing device causes the flare to be ejected from the projectile and ignited. It falls slowly, supported by a parachute. The illuminating projectile is the only pyrotechnic fired from a gun. The light of its flare is intended to illuminate the target and make it easier to aim other guns.

Signaling Devices

Three important pyrotechnic signaling devices are signal lights, Navy lights, and distress signals. Signal lights (often called by their older name of Verylights, but not because they are very light) look like shotgun cartridges, and are fired from a special small projector or a special pistol to a height of about 200 feet, at which time a red, white, or green "star" or small flare ignites and burns for 5 to 7 seconds. The Navy light is a hand-held flare, either blue or red, which burns steadily for 1 to 3 minutes. The distress signal is a hand-held double-ended affair which functions, like the famous pyre in Exodus, to produce smoke (orange colored) by day (from one end) or a bright light by night (from the other end).

CHEMICAL AGENTS

Chemical agents are of five main types, as described below. They may be used in any of several types of ammunition (depending on the

target and the effects desired), or may be released as free liquids or gases from projectors or sprayers. The types are:

Group A. Persistent vesicants. Vesicants blister the skin. The usual ones are mustard gas and lewisite. (Physically, both of these are liquids, not gases.)

Group A-1. Nonpersistent lethal gases. These gases, such as phosgene, injure the body when applied externally, breathed, or taken internally.

Group B. Lacrimators and smokes. A lacrimator such as CN causes weeping and irritation of the throat and lungs. Smokes such as FM and FS are used for screening but have an irritant and, in enclosed spaces, a toxic effect.

Group C. Spontaneously inflammable agents which can be used as incendiaries, such as WP (white phosphorus).

Group D. Readily inflammable mixtures such as TH (thermite), or napalm, a syrupy gasoline-plastic mixture, both of which burn rapidly and with extreme heat and are used as incendiaries.

Chemical warfare is a specialized field which calls for considerable special training. The storage of chemicals requires extraordinary safety precautions. Although poisonous gases were not used in World War II, the Navy was prepared for defense and for reprisal in case the enemy initiated such tactics. Chemical warfare creates many problems in ship protection and decontamination which are the responsibility of the Damage control officer and are outside the scope of this book.

DEMOLITION

Explosives intended for such uses as blasting, eliminating hazards to navigation and obstacles to amphibious landing, and destroying gear to prevent capture by the enemy, comprise demolition material.

Demolition techniques are taught in special Navy schools and will not be discussed in detail in this text. For major blasting operations, various forms of dynamite are used; but dynamite normally is not carried aboard ship.

Half-pound demolition charge blocks, consisting of either pressed TNT or cast TNT and tetryl, are issued to ships for general use. Large demolition charges, also consisting of TNT, and assembled with half-pound booster charges, are also issued for major projects, such as scuttling vessels. Charges of both of these types are detonated by means of blasting caps, set off by electric current.

Highly classified instruments must be completely destroyed if capture or abandon ship is imminent. They are therefore equipped with tiny bombs called destructors, which can be actuated at a moment's notice. Usually, they contain lead azide or TNT-tetryl, with appropriate electric ignition elements.

AMMUNITION

In a general sense, ammunition includes anything that is intended to be thrown at the enemy or put in his path, to deter, injure, or kill his personnel, or to destroy or damage his materials. In this book, the term is used in a much narrower and more technical sense. Ammunition includes any projectile or explosive weapon, as well as components or parts thereof, but not guns or weapon launchers and their parts.

The next section is devoted chiefly to gun ammunition. Other types of ammunition to be taken up later in this book include mines, torpedoes, antisubmarine weapons, bombs, rockets, and grenades. This book, as mentioned in chapter 1, does not cover two other types of ammunition—nuclear weapons and guided missiles.

Service ammunition is ammunition fit for service use and including all explosive and propellant components. Inert (i.e., lacking explosive and propellent components) and partially inert ammunition of several types is used for test, training, and practice purposes. Dummy or drill ammunition (completely inert) which resembles service ammunition in appearance, size, and weight, may include functioning components that contain no explosive or propellant. It is used for training and test purposes. Cutaway ammunition (completely inert) has a section cut away to show inner construction and components; it is used for training and display purposes. Plaster-loaded or sand-loaded ammunition lacks the explosive burster charge, but is otherwise not inert; it is used for target practice and for testing of launchers, mounts, or projectors.

Two miscellaneous types of ammunition deserve brief mention for the sake of completeness. They are trench-warfare ammunition and blank ammunition. Trench-warfare ammunition includes hand and rifle grenades, mortar projectiles, and similar infantry weapons (issued

to Marines and landing forces) for ground combat. Black ammunition is a type of gun ammunition with propelling charges but no projectile; it is used for saluting batteries, signaling, and training.

TYPES AND COMPONENTS OF GUN AMMUNITION

Components of gun ammunition are called ammunition details, and all the ammunition details required to fire one shot are said to comprise a complete round. Ammunition details include propelling charges, projectiles, primers, boosters, cartridge cases, etc.

Gun ammunition comprises four types: bag, semifixed, fixed, and small arms (fig. 4-3). The distinction between the first three depends on the manner in which the charge is assembled. In bag (formerly called separate-loading) ammunition, the primer, propelling charge, and projectile are separate units. In semifixed ammunition, the primer and propelling charge are contained in one unit, while the projectile is separate, so that the complete round comprises two pieces. In fixed ammunition, all three components are assembled in one unit. Small-arms ammunition, used in small-arms weapons, will not be discussed in this text.

The principal components of gun ammunition are propelling charges and projectiles. The propelling charge functions to develop thrust that ejects the projectile at the proper initial velocity or I.V. (defined as the velocity, generally measured in feet per second or fps, at which the projectile is moving at the instant it leaves the muzzle of the gun). The projectile generally contains explosive, or it may contain an inert filler or no filler. The propelling charge as an assembly is considered to include the propellent train as well as the propellant itself with its container. The projectile as an assembly includes the fuze, the burster, and the explosive train, as well as the projectile body.

Bag Type Propelling Charge

A complete round of bag ammunition (fig. 4-3A) consists of three separate ammunition details as follows:

1. A lock combination primer (so called because it fits into a firing mechanism called a firing lock, and has a combination arrangement which enables it to fire either on an electric firing impulse or by percussion).

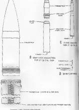

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Figure 4-3. — Complete rounds of gun ammunition. A. Bag. B. Semifixed. C., D. Fixed.

2. Two or more powder bags.

3. A projectile.

Large guns must burn large quantities of propellant to develop the projectile initial velocity required. In a gun as large as 16-inch, several hundred pounds of propellant are needed for one full service round. By dividing this into several fabric bags, each of which can be handled by one man, the gun can be loaded in a relatively brief time. Each bag is made of silk (because silk will burn without leaving a smoldering ash), has silk straps for handling and silk lacing to cinch it up, and is red-dyed quilted silk pockets at one end has coarse black powder to serve as the igniter in the propellent train. The bags

are kept in airtight steel tanks until just before use.

Even as late as the beginning of World War II, many naval guns 5-inch and 6-inch in caliber used bag propelling charges. With the increased mechanization of ammunition handling, to which propelling charges in bags are not well suited, the use of bag ammunition has declined until it now is rarely if ever used in the active fleet, and then only in 8-inch turret guns of cruisers.

A complete loaded round of bag ammunition is shown in a cross-sectioned gun in figure 4-4. The primer, a small cylindrical metal container with one end open and the opposite end closed and rimmed, is loaded manually into a firing lock in the breech plug. The projectile is pushed into the gun by a power-driven manually controlled rammer. Next, the gun crew rolls the propelling charge into position for the rammer to push it into the gun behind the projectile. The last step in loading is for the gun crew to close the breech manually by swinging the breech plug into place and locking it. The gun can now be fired. This is done either by passing a small electric firing current through the primer, or manually operating a mechanical percussion device on the firing lock (not illustrated). The primer produces a spit of flame which travels through a bore or vent in a mushroom-shaped spindle in the breech mechanism and sets fire to the igniter in the after end of the rearmost bag. This sets off the remainder of the charge.

After the projectile has left the muzzle, the breech can be opened, and an air blast from a gas ejector clears the gun bore of residual gases. After inspection to verify that there is no burning residue in the bore, the next round can be loaded.

Case Type Propelling Charges

Gun ammunition which has its propellent charge in a metal case or cartridge instead of a bag is called case ammunition. (The term "cartridge" may also be applied to a complete round of small-arms ammunition.) Both semifixed and fixed ammunitions are of this type. The primer in all case ammunition is inserted in the base of the case at the ammunition depot and is not removed or changed aboard ship.

The designs of various sizes of case ammunition are similar, as may be seen from study of figure 4-5. The case assemblies are similar up to the point at which the mouth is sealed. In fixed ammunition the projectile is the seal; a mouth plug is used in semifixed ammunition.

There are four steps in the assembly of case ammunition: (1) priming, (2) loading the propellant, (3) fitting a wad and sometimes a distance piece, and (4) inserting the projectile or mouth plug. In priming, the primer used is either screwed (40-mm and larger) or force-fitted (smaller cartridge ammunition) into the base of the case. The desired weight of smokeless-powder grains is then dumped loosely into the

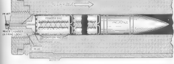

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Figure 4-4.—Complete round of bag ammunition, loaded and ready for firing. Cross section.

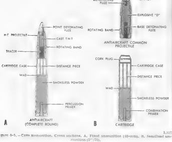

Figure 4-5. – Case ammunition. Cross sections. A. Fixed ammunition (40-mm). B. Semifixed ammunition (5"/38).

case. In 40-mm and larger guns, a cardboard or wad is forced into the case and a distance piece, if one is needed, placed on top. (This prevents shifting of the powder during handling.) The mouth of a semifixed case is then sealed by a mouth plug. In fixed ammunition, the mouth of the case is sealed by forcing the base of the projectile into the case.

The case is cylindrical but tapers slightly from base to top, and has an annular groove and rim at the base end. Cartridge cases have in the past generally been made of brass (hence the term spent brass to designate used cases aboard ship). Steel cases are now the standard in most calibers. Plastic cases are under development. Regardless of what it's made of, regulations require that spent "brass" must be conserved. After a brief ventilation period (to dispose of residual powder gases), it must be stowed until the ship can return it to an ammunition depot to be reused.

The primer-igniter arrangement in case ammunition is different from that in bag ammunition. The primer is always secured to the center of the base of the case. Primers for ammunition of larger caliber than 3" include an igniter

charge (black powder); smaller ammunition generally does not require an igniter, although black powder may be present in the initiator mixture.

Figure 4-6 shows the three types of primer. In percussion primers, the impact of a firing pin (in the gun) on a primer cap imparts a blow to a sensitive initiating mixture between the cap and a metal anvil. This initiates an explosive reaction whose flame ignites the remainder of the primer charge. In electric primers, a brief pulse of firing current heats a small bridge wire

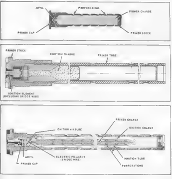

Figure 4-6.—Case primers. A. Percussion primer. B. Electric primer. C. Combination primer.

which ignites the initiating mixture; the flame thus produced is transmitted to the ignition charge, which in turn sets off the propelling charge. The combination primer has both a bridge wire and the cap-anvil arrangement; either can start the reaction. Electric firing is preferred with combination primer ammunition.

PROJECTILES

The projectile is the part of a complete round of service gun ammunition that is expelled at high velocity from the gun bore by the burning of the propelling charge. Modern projectiles are cylinders with pointed noses. Such a projectile can give stable ballistic performance only if it spins about its long axis while in flight — otherwise it will tumble erratically. As will be explained later in further detail, the bores of modern guns are spirally grooved (rifled) so that the projectile will develop this spin as it travels along the bore.

Modern small-arms and machine gun projectiles often consist of solid metal; projectiles used in larger guns, however, are assemblies of several components. The three essential parts are the metallic body, the explosive bursting charge, and the fuze which sets off that charge. There may also be a tracer to make the projectile more readily visible during flight.

The solid bullet damages by impact alone. Assembled projectiles, however, inflict damage primarily by the blast of the high-explosive charge and resulting high-velocity fragments.

EXTERNAL FEATURES OF PROJECTILES. The external shape of the projectile is designed to obtain the desired flight characteristics of stability and minimum air resistance. The form of forward end which best fulfills these conditions is the ogival curve (generated by revolving an arc of a circle about a chord). In a projectile the chord is the axis of the projectile and the radius used is about nine times the diameter (caliber) of the projectile. In small-caliber projectiles a cone is sometimes used instead, but this part of the projectile is still called the ogive. Abaft the ogive the projectile is cylindrical. The cylindrical shape may continue to the base (making a square base); or the after portion may be slightly tapered, (making it boat-tailed). Near the after end of the projectile is the rotating band; forward of this is the bourrelet (fig. 4-7). These two surfaces, slightly larger in diameter than the body, support and steady the projectile in its passage through the gun.

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Figure 4-7.— External features of gun projectile.

In small projectiles the entire body forward of the rotating band may be finished to bourrelet diameter. On large-caliber projectiles additional bourrelets, forward of the rotating band, are added to provide better support. The bourrelet is very slightly smaller (0.015 to 0.030 inch) than bore diameter.

The rotating band, on the other hand, is actually larger than bore diameter. Its three main functions are (1) to seal the bore, (2) to position and center the rear end of the projectile, and (3) to engage the helical rifling grooves in the gun bore so as to impart rotation to the projectile. It also holds the projectile in position in the gun after loading and ramming so that it will not slip back when the gun is elevated.

Rotating bands are generally made of copper, either pure or alloyed. (Experiments have been made with rotating bands of sintered metal; these have not been adopted for service at present.)

Projectile Identification

Distinguishing colors and markings are necessary to properly and rapidly identify projectiles. Identification of Ammunition, OP 2238 (latest revision), serves as a guide for identifying by color, markings, and lettering projectiles and other Navy ammunition.

Presently there are two different color-coding systems used by the Navy to identify ammunition. These systems are classified as the old and the new system and are explained in OP 2238. The old system applies only to ammunition manufactured before the new system of color coding became effective. All projectiles (and other ammunition) newly produced must have the new color code and markings applied.

Projectile Weight

Within limits, a gun can fire projectiles of different weights. The weight of U.S. Navy projectiles is determined by the formula

$$W = \frac{d^3}{2}$$

in which: W = weight of projectile in pounds, and
d = caliber of gun in inches.

The weight of the projectile per square inch of bore is called sectional density. It is represented by the expression

$$SD = \frac{W}{A}$$

in which: SD = section density.
W = weight of projectile in pounds.
A = area of bore, including grooves in square inches.

This ratio varies with the size of the gun, averaging approximately six-tenths of the caliber.

The distribution of weight in a projectile is a matter of considerable importance. The center of gravity should be in the longitudinal axis and close to or abaft the center of form.

Classification of Projectiles

All gun projectiles, other than small arms, share the characteristics so far described. Since targets differ in character, projectiles must differ in design to defeat them most effectively. There are three general classes of projectiles:

1. Penetrating.
2. Fragmenting.
3. Special purpose.

In each class are one or more types, each designated by a specific letter code.

Penetrating projectiles. Penetrating projectiles include armor-piercing (AP) and common (COM). They are designed to penetrate, respectively, heavy and light armor. The usual bursting charge for these types is Explosive D, which is insensitive enough to permit penetration without premature detonation.

Figure 4-8 shows the construction of a typical AP projectile. The body has thick walls, a relatively small burster charge cavity, a nose cap,

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Figure 4-8. — 3-inch armor-piercing projectile. Cross section.

and a thin metal windshield. To function effectively, an armor-piercing projectile must keep its burster charge intact until it has penetrated its target. The projectile body, of tough steel, backs up the hardened but somewhat brittle steel nose cap, which is so shaped that it will dig into and cut through an armor-plated target, rather than ricochet. However, in flight the blunt nose cap, which is shaped for penetration of armor, not for streamlining, would give the projectile the ballistics of a brick. Hence the windshield, which collapses upon impact with the target, is screwed on to give the exterior of the projectile a satisfactory ogival shape. AP projectiles in larger calibers are not efficient against lightly armored targets, because of their small bursters. The projectile is delay-fuzed to burst after penetration.

The common projectile, illustrated in figure 4-9, has a hood instead of the armor-piercing cap, a larger burster, and thinner walls, and is suited for more lightly armored targets than AP projectiles.

Fragmenting projectiles. Fragmenting projectiles are designed to damage by both blast effect and fragmentation — that is, breaking up

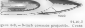

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Figure 4-9. — 3-inch common projectile. Cross section.

into high-velocity fragments. Such projectiles characteristically have relatively thin walls and large cavities for the burster. Under this general classification are the following types:

1. High-capacity (HC). A typical HC projectile is illustrated in figure 4-10. This type is used against unarmored surface targets, shore objectives, or personnel. Since no penetration ability is required, explosives more sensitive than Explosive D may be used.

2. Antiaircraft (AA) projectiles are designed for use against airplanes in flight. Except for fuzing they are substantially the same as HC in the larger calibers. In smaller sizes the explosive often contains an incendiary element.

3. Antiaircraft common (AAC) projectiles are a dual purpose design, combining the qualities of antiaircraft projectiles with the toughness necessary to penetrate steel plating not of armor thickness. The type of fuzing will depend on the use. The walls may be heavier than those of the other thin-walled types, and the filler is usually Explosive D.

Special purpose projectiles. The special purpose classification includes types not intended to inflict damage by blast or fragmentation. If the filler includes any explosive, it is a small charge designed to expel the contents of the projectile. See figure 4-11. The common varieties are:

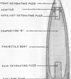
1. Illuminating (ILLUM) projectiles, often called star shells (SS), contain a bright flare attached to a parachute; these are expelled from the projectile by a small black-powder charge which also lights the flare. As the parachute slowly lowers the flare, it illuminates the target.

2. Smoke projectiles contains tubes of white phosphorus (WP) which are scattered and burst by a small black-powder charge. White phosphorus produces a screening smoke, and has an incendiary effect.

3. Window (W) projectiles contain metal foil strips, which are scattered high in the air by a small burster charge to confuse enemy radar.

4. Nonfragmenting ("nonfrag") projectiles are used for antiaircraft gun practice. They contain a smoke-producing substance, available in various colors, to make observable bursts without destroying the target by fragmentation.

5. Target or blind-loaded (BL) projectiles contain sand or other inert substance to give the same weight and balance characteristics as explosive fillers.

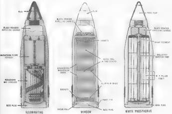


110.6
Figure 4-10.—5-inch high-capacity projectile.

Rocket Assisted Projectiles

A rocket assisted projectile (RAP) is fired from a gun at the same initial velocity as a standard projectile. The RAP is not a replacement for existing gun-type ammunition but an addition to it that extends its range several hundred yards. Rocket assisted projectiles are used primarily against personnel and light-materiel shore targets. A secondary use, however, is against enemy shipping at extended ranges. Operational skill and maintenance level required aboard ships are not affected by the addition of the RAP.

RAP DESCRIPTION.—Each RAP round consists of a projectile and a gun cartridge (full charge). The projectile consists of a solid-propellent rocket motor with a delayed ignition element, an explosive filler warhead, and either a controlled variable time fuze (CVT) or a point detonating fuze (PD). Cartridges used to fire RAPs are the same as those used to fire standard projectiles. Figure 4-12 is a cutaway view of a 5"/38 rocket assisted projectile.



110.47
Figure 4-11.—Special-purpose projectiles.

RAP OPERATION.—When the projectile is fired, gun chamber pressure flexes a spring which strikes a percussion primer assembly in the base of the projectile. The primer in turn ignites a pyrotechnic delay column that burns for a definite period of time (23 seconds for a 5"/38 RAP). After the delay period, the delay column burns the ignition charge which ignites the rocket motor. The rocket motor gives the projectile a "boost", increasing its velocity and its range. The details of the ignition element used in the RAP are illustrated in figure 4-13. The igniter is a gun-gas-triggered, percussion-initiated delay igniter, sealed into the base of the motor case and blown out upon motor ignition.

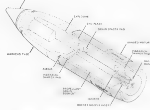
SAFETY PRECAUTIONS.—RAP ammunition should be handled carefully at all times. Stowage conditions for RAPs must meet the same requirements applicable to standard projectiles.

Because of the similarity in appearance between a standard projectile and a RAP and the dissimilarity of impact points, positive and correct identification by handling crews becomes a major safety factor. For example, crews could be under the impression that they are firing RAPs over the heads of our assault forces when actually they are firing standard projectiles into the midst of those forces.

FUZES

A projectile fuze is a mechanical or electronic device which will detonate or ignite a charge in a projectile at the time and under the circumstances desired.

Fuzes may be classified according to function (impact, time, auxiliary, or proximity), the position of the fuze in the projectile (nose or base), type of mechanism or principle utilized (mechanical time or variable time—VT), and specific



84.304
Figure 4-12. — 5"/38 rocket assisted projectile (RAP); cutaway view.

84.305
Figure 4-13. — Ignition element; cutaway view.

action at time of functioning or initiation (ignition or detonation). Figure 4-14 illustrates locations of typical fuzes.

Typical examples of nomenclature for Navy fuzes are as follows:

1. Auxiliary detonating (ADF).
2. Base detonating (BDF).
3. Mechanical time (MTF).
4. Point detonating (PDF).
5. VT or proximity (VTF).

Point detonating, time, and VT fuzes may all be called nose fuzes because of their location in the projectile. Fuzes are designated as detonating when they contain within themselves a high-explosive charge sufficient to set off a high-order explosion in the burster. Ignition fuzes contain black powder sufficient to ignite the burster of small projectiles. In larger projectiles such fuzes function indirectly through an auxiliary detonating fuze.

For safety reasons a fuze must be inoperative until the projectile is clear of the muzzle and the firing ship. A fuze is said to be armed when it is set to permit initiation of the explosive train. It is unarmed when set to prevent initiation.

A satisfactory fuze must:

1. be safe to handle; that is, the fuze must not arm if dropped or joggled.

2. be safe after firing until it is at a safe distance beyond the gun bore. A fuze with this characteristic is said to be boresafe.

3. function to initiate the explosive train at the proper instant, and not before or too late.

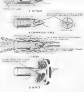
84.13
Figure 4-14.—Fuze locations.

Forces That Operate Fuzes

From the instant of firing until it strikes its target, a projectile and its components are subjected to a succession of forces that can be utilized to start or drive a fuze's mechanism. Many fuzes are complicated and use more than one of these forces (listed below), in addition to other energy sources.

1. SETBACK. When the propelling charge is fired, the projectile is (a) accelerated forward and (b) twisted clockwise (as seen from the base). Because of their inertia, movable parts of the projectile consequently develop, during the period of projectile acceleration and twist, a rearward force called setback (fig. 4-15A) and a rotational force or torque in the counterclockwise direction (i.e., in the direction opposite to the twist). This torque is called angular setback.

2. CENTRIFUGAL FORCE. In accordance with Newton's laws of motion, any moving particles



84.12
Figure 4-15.—Forces that work on fuzes. A. Setback. B. Centrifugal force. C. Creep. D. Impact.

tends to keep moving in a straight line. Consequently, because of its inertia, a revolving particle develops a radial thrust (centrifugal force) away from the center of revolution. As shown in figure 4-15B, the fuze parts therefore develop a continuous outward thrust from the rotating projectile's centerline while it is in flight.

3. CREEP. The projectile while in flight is gradually slowed by air resistance acting on its exterior surface. Since the parts inside the projectile are not in contact with the air and do not meet this resistance, they tend because of inertia to continue in motion at the same velocity. Thus, as illustrated in figure 4-15C, they exert a continuous forward thrust, called creep.

4. IMPACT. When a projectile strikes, its parts because of inertia tend to continue moving forward; this develops considerable force. Impact is generally used to initiate the explosive train (fig. 4-15D).

5. TARGET CONTACT (not illustrated). When a firing plunger or other part of a projectile contacts the target, it is driven toward the rear with respect to the remainder of the projectile. Target contact is used to start the explosive train.

Types and Applications of Fuzes

Auxiliary detonating fuzes are used in conjunction with all types of nose fuzes in projectiles of 3-inch and greater caliber except illuminating and special purpose projectiles. They prevent detonation if the nose fuze is accidentally actuated before the auxiliary detonating fuze is armed.

Base detonating fuzes are used alone in AP and COM projectiles, and in combination with nose fuzes in such dual purpose projectiles as AAC and HC. In the latter their functioning is completely independently of the nose and auxiliary fuzes. All base detonating fuzes function on impact; some, however, have a delay time (0.02 to 0.033 second) after the projectile hits, to allow time for armor penetration.

Mechanical time fuzes (MTF) are clockwork mechanisms which begin to function upon firing, and initiate the explosive train at a selected time following firing. They are used in high explosive, illuminating, and various special purpose projectiles. When used in high explosive projectiles, these fuzes work in conjunction with auxiliary detonating fuzes. MTFs contain a gear train and an escapement mechanism which starts to operate immediately after the inertia force of setback has ceased. Centrifugal force acting on weights, with or without the aid of coiled springs, supplies the energy to run the clock mechanism. After the predetermined and preset time interval, a spring-loaded firing pin is released and strikes the initial element of the fuze explosive train.

MTFs are used in projectiles with high fragmentation qualities to provide air bursts. Air bursts are effective against personnel if they are timed to burst, say 50 feet above a trench or other occupied area. Gunfire support requirements call for these bursts to be 25 to 50 feet above the target.

Even though they can be used in antiaircraft fire, MTFs are used more often against surface or shore targets. Obvious is the superiority of timed projectiles, throwing fragments in all directions, over those which require target contact before detonation. A direct hit is improbable on a small, fast-moving target, but the 5" AAC projectile has been designed to increase the probability of a hit by utilizing a timed air burst. An AA common projectiles may have a point detonating fuze, a base detonating fuze, auxiliary detonating fuze, and mechanical time fuze making it a very versatile projectiles.

Point detonating fuzes are designed to function on impact. They are faster acting than BDFs and are used chiefly against lightly armored targets in gunfire support. Point detonating fuzes are found in high capacity (HC), AAC, and white phosphorous (smoke) projectiles. These fuzes are inserted into the projectile's nose in an unarmed condition; they are armed by centrifugal force after the projectile has been fired.

VT fuzes are proximity fuzes, used in all of the types of projectiles that can use mechanical time fuzes, except illuminating and window. The VT fuze is a self-contained radio transmitter-receiver which receives echoes of its transmission as reflected by a target. When the returning signal is of sufficient strength, as the projectile nears the target, the firing circuit closes. The fuze is rugged and compact; it fits into the nose of a projectile.

VTs are also effective against personnel ashore but are used mainly against air targets. If a VT bursts in the vicinity of an air target, it is considered to be a hit in wartime firing and for peacetime firing practice evaluation. The burst is called a TTB (target-triggered-burst).

CHAPTER 5

GUNS, GUN MOUNTS, AND TURRETS

INTRODUCTION

The gun has been used in warfare ashore and afloat for several hundred years. Its effectiveness as a weapon has increased over this period, but this development has not been a slow, steady growth. For the first 400 years the technology of gunnery changed so little that a sailor of early Elizabethan times would have had to learn very little that was new to have served a gun at Trafalgar (1805). Most of the basic features that have made the modern Naval gun the effective weapon it is today were developed in the past 115 years; most of them began to become important only after 1900.

The guns aboard modern United States Naval vessels, complex though they are in detail, are based on a relatively few fundamental features. Once these are grasped, the student will find it easier to understand the details of structure of any gun mount or turret he encounters.

The fundamental principles of how guns, gun mounts, and turrets are constructed and how they work is explained in the first part of this chapter. Details of their construction and functioning are described later in the chapter.

Features of gun mounts and turrets that are discussed in the following paragraphs are those that are referred to in this book as "conventional," which means that they represent standard practice in the gun and mount design as it existed in the U.S. Navy about the middle of the 20th century. New developments and improvements in guns and mounts are, of course, always in progress.

SOME BASIC DEFINITIONS

Before proceeding with the study of gun mounts and turrets, study the following brief list of definitions. They amplify or more precisely define some terms to be discussed later in the chapter. Other definitions may be found in the appendix glossaries.

GUN.—The term GUN properly designates the tube or barrel, but it is commonly used to refer to the whole assembly of which the barrel is but a part.

MOUNT.—The mount is the entire structure between the gun and ship's structure. It supports the gun, secures the gun to the ship's structure, and provides for the gun's elevation, train, and (in guns larger than 20-mm) recoil and counterrecoil. There are several types of mounts, but all of them must accomplish these functions. Larger mounts have other functions as well.

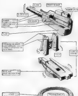
TRAIN.—Train angle of a gun is the position of the axis of the gun's bore in a plane parallel to the deck measured from the ship's centerline. Training the gun is rotating the gun in bearing. The trainer is the gun crew member who controls the training of the gun. The training gear is the equipment used to train the gun.

COMMON STRUCTURAL ARRANGEMENT OF NAVAL GUN MOUNTS

Figure 5-1 shows the "skeleton" of the structure of a typical 5-inch naval gun mount. In general these parts, their arrangement, and their nomenclature are typical of other naval gun mounts, both larger and smaller.

Serving as the mount foundation is the stand, a steel ring bolted to the deck. The training circle is an internal gear inside the stand.

Supported by the stand, and capable of rotating in train in roller bearings on it, is the base ring, also called the deep section ring or lower carriage. Mounted on it is the upper carriage



84.137
Figure 5-1.—Main assemblies of a 5-inch mount. Exploded view.

a pair of massive brackets braced to hold the trunnion bearings, large roller bearings into which the gun trunnions fit. The trunnions are part of the slide, a rectangular weldment which supports all the elevating parts of the gun. The housing slides in recoil in the slide; the barrel fits into the housing's forward end, and the breechblock can slide up and down in a breechway just behind the barrel. Arrows show the movement of which each part (except the breechblock) is capable.

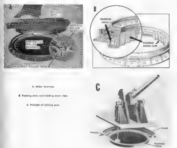
Figure 5-2 shows how the base ring fits into the stand, and how the mount trains. Holding-down clips bolted to the base ring fit under the stand so that the carriage will not tip when the gun fires or when the ship pitches and rolls. The base ring can turn on the stand in two large-diameter roller bearings. One, the roller path, takes up vertical thrust, the other, horizontal. The function of the training circle also is illustrated in figure 5-2. A pinion in the carriage engages the training circle gear teeth to train the mount.

The carriage assembly comprises two parts—the lower carriage (base ring) and upper carriage (fig. 5-3). The base ring supports the upper carriage and platform; the shield (in enclosed mounts) is secured to it. It also supports the mount power drives and other components. In mounts equipped with powder and projectile hoists, the hoists hang from the base ring and train with the mount. The upper carriage supports the trunnion bearings. The trunnion bearings and trunnions, besides supporting the elevating parts, provide connections for air lines (for gas ejection) and mechanical linkages (for percussion firing and for transmission of elevation movement to firing stop mechanisms).

The trunnions are part of the slide (fig. 5-4). The slide is conventionally a rectangular steel weldment which houses or supports all the parts of the gun and mount that move in elevation. In modern mounts designed to engage either air or surface targets, the limits of elevation movement are from minus 10 to 15 degrees (that is, with gun barrel depressed 10 to 15 degrees below the horizontal) to about plus 85 degrees (that is, with the gun barrel within 5 degrees of pointing straight up).

The slide (fig. 5-4) contains the ammunition feed mechanism (or the power rammer if ammunition feed is performed manually with mechanical assistance), the recoil brake, the counterrecoil mechanism, the elevating arc, and the gun housing. Figure 5-4 shows how the elevating arc positions the slide in elevation. The arc, a gear sector secured to the slide, engages a pinion (which may be driven manually or by a power drive) in the carriage.

As you know from the last of Newton's three laws of motion, any action produces an equal and opposite reaction. The thrust which propels the gun projectile out of the barrel is accompanied by an equal thrust in the opposite direction. This thrust produces a rearward movement, called recoil, of parts of the gun. After the projectile and high-pressure propellant gases have left the barrel, recoil thrust ceases. The recoiling parts of the gun are then forced forward. This forward movement is called counterrecoil, and it continues until the parts that recoiled are restored to their original position before firing.



A. Roller bearings.

B. Training circle and holding-down clips.

C. Principle of training gear.

84.138-.152

Figure 5-2.—Details of the stand and carriage.

This is called battery position, and the gun is now said to be in battery. Note that in all modern naval guns, only parts of the gun mount recoil; the gun mount as a whole does not recoil with respect to the ship's structure.

The recoiling parts of a conventional naval gun are either attached to or housed in the gun housing or breech housing (fig. 5-3). (Some turret guns and 20-mm guns differ considerably from this type of conventional design; this description is not intended to apply to them.) Secured to the forward end of the housing is the gun barrel itself. The commonest method of attaching gun to housing is by use of an interrupted-screw joint, with a key to lock the barrel against possible rotation. The housing can move parallel to the gun bore axis in WAYS in the slide. It is normally forced to the battery position by a counterrecoil mechanism (described later).

When the gun fires, the reaction of the barrel forces the housing aft; this movement is opposed by the counterrecoil mechanism and by a hydraulic recoil brake to be described later.

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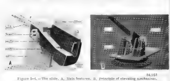
Figure 5-3.—The carriage. A. Upper and lower carriage. B. Trunnion bearings.



84.163
Figure 5-4.—The slide. A. Main features. B. Principle of elevating mechanism.

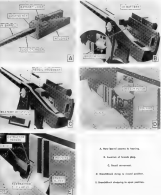
Figure 5-5 also indicates the location and some features of the breech mechanism. The conventional type, illustrated here, is called the vertical sliding-wedge type.

DESIGNATION OF GUNS BY CALIBER

The caliber (bore diameter) of U.S. Naval guns is expressed in inches or millimeters. The length of guns of 3-inch caliber and above is usually expressed calibers that are equal to

$$\frac{\text{length of gun in inches}}{\text{diameter of gun in inches}}.$$

Thus a gun with a bore diameter of three inches and a length of 150 inches would be designated 3"/50 caliber ($\frac{150''}{3''} = 50$).



A. How barrel secures to housing.

B. Location of breech plug.

C. Recoil movement.

D. Breechblock rising to closed position.

E. Breechblock dropping to open position.

84.140
Figure 5-5. — The housing.

Guns most likely to be found on Navy ships today, in the active and/or the reserve fleet, are:

Guns	Carried on
* 16"/50 cal.	Battleships.
8"/55 cal.	Heavy cruisers.
6"/47 cal.	Light cruisers; guided missile cruisers.
5"/54 cal.	Large carriers; destroyers; frigates; tactical command ships.
5"/38 cal.	Battleships; cruisers; destroyers; carriers; destroyer escorts; auxiliaries.
3"/50 cal.	Any ship from patrol craft to battleship.
40-mm	
20-mm	

*Reserve fleet only.

SIGNIFICANT FEATURES OF MODERN GUNS AND MOUNTS

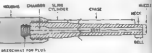
The effectiveness of modern guns, as contrasted with the primitive naval weapons mentioned at the beginning of this chapter can be attributed directly to the following significant and characteristic features:

1. Improved metallurgy and barrel construction.
2. Rifling.
3. Breech-loading mechanisms.
4. Percussion and electrical firing systems.
5. Recoil and counterrecoil systems.
6. Power-driven ammunition hoists.
7. Power rammers and mechanical ammunition feed.
8. Safety features—salvo latch, safety link, gas ejection.
9. Sighting and fire control equipment.
10. Power drives for elevating and training.

GUN BARRELS

Figure 5-6 shows in cross section a typical modern gun barrel.

At the rear or breech end of the gun is a breech housing, which houses the breechblock or plug; this can be opened for loading and closed for firing by a breech mechanism of which it is an important part. Just forward of the plug is an enlarged chamber that holds the



84.13
Figure 5-6.—Main parts of a gun barrel. Cross section.

propelling charge. The forward end of the chamber tapers down to the bore, which has a constant diameter to the front or muzzle end of the gun. In all but a few special purpose guns the bore is rifled—that is, a set of spiral grooves is engraved into its surface. In larger guns, which tend to wear more rapidly per round fired than smaller weapons, the rifling is cut in a liner which can be replaced when worn.

The bulkiest part of the gun is at its breech end, where the metal is thickest to withstand high propellent gas pressures. The cylindrical after part of the barrel is the slide cylinder, which moves in bearings in the slide during recoil. Forward of the slide cylinder the barrel tapers (this tapering part is the chase), then (in many gun designs) thickens to form a bell, which discourages any tendency for the metal to split. The narrow part of the barrel just aft of the bell is the neck. In newer gun designs the muzzle has no bell, but may have lugs which serve to anchor a jack used in replacing the liner.

All modern gun barrels are of steel, and they are generally prestressed to make them more resistant to internal pressures. Prestressing methods will be discussed in further detail later.

RIFLING

Early cannon were smoothbores and generally fired round (spherical) shot. Other things being equal, a light projectile will travel a lesser distance, and be more affected by wind and air resistance, than a more massive one. Since the maximum volume of a sphere depends on its radius, the mass of the early gun projectile was limited by the density of its material. An elongated projectile can, of course, be made more

massive by making it longer, but it will be unstable and erratic in flight—unless it can be made to spin on its long axis.

Figure 5-7 shows how this problem is solved in a modern naval gun. The projectile is elongated, with an ogival forward end. The gun bore is rifled, and the rifling grooves are helical or spiral (fig. 5-7, part A). In all naval guns and small arms except the .45 caliber pistol, the rifling has a right-hand twist. The twist may be uniform (generally around 1 in 15 or 20 times the bore diameter), or increasing (as in the 40-mm gun) so that the twist becomes sharper as it nears the muzzle.

The caliber of a rifled gun is measured from the top of one land (the high surfaces between grooves) to that on the opposite side of the bore. Since the rotating band for the projectile is slightly larger than the nominal gun bore diameter, the rifling cuts into or engraves the softer metal of the rotating band when the projectile is rammed (fig. 5-7, part B). When the gun is fired, the projectile spins at an increasing rate as the propellent gas accelerates it. (With right-hand twist in the rifling, the spin is clockwise as viewed from the breech.) Moreover, because of the close fit between rotating band and rifling, the gas is sealed behind the projectile. Figure 5-7, part C, shows how a projectile might look as it leaves the muzzle, spinning rapidly and with rotating band deeply engraved.

BREECH MECHANISMS

The breech mechanism comprises the breechblock or plug that closes off the after end of the gun, and the linkages and other mechanical parts required to operate it. The breech mechanism, as it happens, invariably incorporates part of the firing system.

All naval guns other than small arms (which are not taken up in this book) utilize one of two principles of operation in their breech mechanisms. The older, and nowadays by far the less used, is the interrupted-screw breech mechanism. The newer is the sliding-wedge breech mechanism.

Only bag-type guns use the interrupted-screw breech mechanism in today's Navy, and only a few heavy cruisers have bag guns. This type of breech mechanism will therefore not be described in this text. Sliding-wedge breech mechanisms are used in all present guns larger than small arms, up through 8-inch caliber. Larger case guns (6-inch, 8-inch, and the automatically loaded

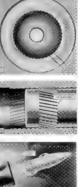


Figure 5-7.—Rifling. A. Rifled bore (viewed head on). B. Rifling engraves the rotating band. C. Projectile spin in flight. 84.143

5-inch Mk 42) use hydraulically actuated sliding-wedge breech mechanisms. In other guns the sliding-wedge breech mechanism is driven through the camming action during recoil and counterrecoil.

FIRING SYSTEMS

Figure 5-8 shows the principal commonfiring system elements that are housed in the breechblock of a case gun 40-mm or larger. The 40-mm mechanism and the mechanisms of a few obsolescent hand-loaded 3-inch guns are capable only of percussion fire. 5-inch guns earlier than Mk 42 are capable of either percussion or electrical fire as desired, and all other case guns now in service are designed for electrical fire only (except for special "short cases" used to clear a gun by percussion fire in an emergency).

Common to all case gun firing systems is the firing mechanism (also called the firing lock) in the breechblock (fig. 5-8). This is secured in the breechblock, but is not considered part of the breechblock, and is easily removed for servicing or replacement. In combination and electric firing systems the firing pin is electrically insulated and is part of the electric firing circuit. The pin makes contact with the primer of the loaded propelling charge case when the gun is loaded and the breech is fully closed. The pin is withdrawn into the breechblock when the breech is not fully closed. In combination and percussion firing systems the firing pin can deliver a blow on the primer when actuated by a mechanical firing linkage, provided the gun is in battery, and the breech is fully closed.

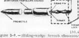


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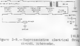
Figure 5-8. — Sliding-wedge breech elementary firing mechanism.



110.50
Figure 5-9. — Representative electrical firing circuit. Schematic.

ELECTRIC FIRING CIRCUITS. — The firing mechanism proper — which has as electrical elements only an insulated firing pin and a quick-disconnect terminal to which a firing lead or cable is attached — is only the final part of the electrical firing system.

Figure 5-9 shows schematically the elements that will be found in a typical electrical firing system for a mount or turret. The diagram does not show the physical locations or appearance of the elements.

Under normal service conditions, guns fire by using the ship's 115 v, a-c supply. Trace the circuit beginning with this source. Switches (not shown on the schematic) in the fire control plotting room (plot) determine where control of remote fire will be placed. That is, whether the director or plot has control. There are spring-loaded normally open firing keys at each station which can assume control. These are all on the 115-volt line to the primary of the firing transformer at the mount. The mount captain, when told to do so, operates his firing selector switch to the "plot" (meaning remote) or to the "local" position. In "local" the primary supply is always present in the firing transformer.

The firing transformer's secondary leads 20 v. a-c to a firing selector switch at the mount. This switch has two positions, "battery" and "motor-generator." Batteries in these circuits, while still part of the schematic, are no longer installed due to the extra maintenance they require. So, this firing selector switch will always be in the motor-generator position except during maintenance.

The pointer's firing key is generally on one of the elevating handwheels and is connected to the circuit by a flexible cable. The firing stop mechanism switch is part of the firing stop

mechanism (to be described later). It opens the firing circuit when the gun endangers part of the ship's structure. Some mounts have no interlock switch or relay, but such interlocks are common with automatic loading equipment or hydraulically operated breech mechanisms. The one shown in the schematic may represent up to six or more, each of which registers that a certain mechanism or part is in a position that is safe for firing. The breech-closed contact is a common variety of interlock. In addition (and not shown in the schematic) are the safety devices in breech and firing mechanisms which prevent contact between primer and firing pin when the breech is not fully closed or the gun is not fully in battery.

The last part of the circuit is the firing pin's contact to the electric primer. The circuit is completed through the filament in the primer, the cartridge case, and ground return to the firing transformer.

FIRING STOP MECHANISM.—At any considerable range, the axis of a gun's bore deviates from the line of sight to the target. The greater the range, the greater the deviation. This makes it possible, particularly in enclosed mounts, for a pointer or trainer looking through a telescope to see no obstacle in the line of sight, while the gun's bore may be in line with some part of the ship's structure, so that firing the gun will damage the ship. It is therefore necessary either to prevent pointing the gun bore toward the ship's structure, or to prevent it from firing under these conditions. The latter method is more common. This is the function of the firing stop mechanism, which disables the firing system when the gun is so aimed as to endanger the ship it is mounted on.

Figure 5-10 shows the basic mechanism. It is essentially a plate or disc type cam, in which the inputs are gun train (which rotates the cam) and gun elevation (which moves the cam follower approximately radially across the cam). The elevation input shaft moves toward the center of the cam plate when the gun elevates, and toward the edge when it depresses. At the end of the elevation input shaft is a spring-loaded plunger which contacts the cam plate. Each point on the surface of the cam plate corresponds to a specific position (in train and elevation) of the gun barrel; the complete surface is a profile map of the gun's safe and unsafe firing areas.

When the gun mount is installed, part of the cam plate surface is cut away so that when the

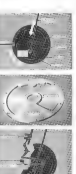


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Figure 5-10.—Principle of firing stop mechanism. A. Mechanical inputs. B. Profile cam plate. C. How fire is interrupted.

gun is in a position where it is safe to fire, the spring-loaded cam-follower plunger will be depressed, while in unsafe positions of the gun, the plunger will be forced upward. Therefore the cam plate areas corresponding to safe firing positions are cut away, and the unsafe areas are not cut. The plotting of a firing cutout mechanism is explained in a later chapter. Figure 5-10C shows how the plunger action can both open the electrical firing circuit and interrupt the percussion firing linkage (if there is one) when it is riding on a high area of the cam.

RECOIL AND COUNTERRECOIL SYSTEMS

Novels about life aboard naval vessels of a hundred years ago or more frequently have a scene in which a naval gun mount breaks loose—either in battle, during a storm, or both—and thunders, an uncontrollable Juggernaut, across the deck as the ship rolls in heavy seas. This is something that can scarcely happen aboard a modern naval vessel; other gear may break loose, but how can a gun mount? Why were not the guns in the days of sailing vessels simply secured to a fixed mounting, as guns are today?

The answer is that modern guns have recoil and counterrecoil mechanisms, and ancient guns did not. A naval gun can be rigidly secured to the deck, but without some provision for its recoil it will break loose when fired.

Note the general functions of recoil brakes and counterrecoil mechanisms:

1. A recoil brake is primarily designed to absorb the force of recoil and "spread" it so that the sudden heavy shock is converted to a thrust exerted over an appreciable distance through which the recoiling parts of the gun are permitted to move. In the mechanical sense, work is done by the recoil force in pushing the gun and housing aft against the resistance of the recoil brake; the energy absorbed in the brake appears as heat.

a. A secondary function of all recoil brakes in naval gun mounts is to bring to a smooth stop the forward movement (counterrecoil) that follows recoil.

2. A counterrecoil mechanism is a device that stores some of the energy of recoil and uses it to force the recoiling parts forward into battery after the projectile has left the gun muzzle. (The energy of recoil can, of course, be traced ultimately to the combustion of the propellant.)

Recoil and counterrecoil mechanisms are designed to work together. Figure 5-11 shows in a general way where the recoil and counterrecoil systems are located in a conventional 5-inch mount.

There are many different types of recoil and counterrecoil mechanisms used in land artillery and elsewhere. The U.S. Navy uses, in naval gun mounts, one general type of recoil brake (in either of 2 variants) and two kinds of counterrecoil mechanism.

RECOIL SYSTEMS.—All present day recoil systems for naval guns larger than 20-mm use hydraulic recoil brakes. A hydraulic recoil brake is a mechanism of the type commonly termed by engineers a "dashpot." Its piston and a cylinder can move with respect one to the other. The liquid in the cylinder can move from one side of the piston to the other, but its rate of movement is restricted or "throttled."

The two variants of this device are shown in figure 5-12. In one variant (A in the figure), the piston is solid, and each cylinder is filled with recoil fluid (usually a mixture of water with glycerin). In the wall or liner of each cylinder are cut three throttling grooves 120° apart. They are shallow at the forward end of the cylinder and deepen toward the after end.

The principle of functioning of the throttling-groove type (fig. 5-12A) was described in chapter 3. The other major type of recoil brake (part B of figure 5-12) uses three fixed tapered throttling rods which pass through orifices or

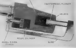

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Figure 5-11.—Recoil and counterrecoil systems in a conventional 5-inch mount. Simplified schematic.

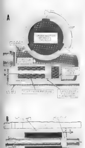

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Figure 5-12.—Hydraulic recoil brakes. Simplified schematic. A. Throttling-groove type. B. Throttling-rod type.

les in the piston. (Only one rod is shown in he figure.) This arrangement functions like the hrottling-groove brake, except that the fluid low is regulated by the varying cross section of the rods in the holes.

COUNTERRECOIL SYSTEMS IN GENERAL.—There are 2 basic types of counterrecoil systems used in United States naval guns. Guns smaller than 5-inch use 1 or more counterrecoil springs. (These are sometimes termed recoil springs in OP's and elsewhere, but the function is the same.) Guns 5-inch and larger use pneumatic recuperators, which depend on compressed gas (generally air or nitrogen) to provide counterrecoil thrust. Since the very high-pressure gas used in such systems is sealed by use of packings under hydraulic pressure, such systems are often called hydropneumatic counterrecoil systems.

The functions of any counterrecoil system are (1) to return the recoiling parts of the gun to battery after recoil, and (2) to hold the recoiling parts in battery. Thus a counterrecoil system must not only provide thrust during counterrecoil, but must also develop enough continuous thrust at all times to hold them there except while the projectile is actually being propelled through the bore. (Recoil brakes develop their "reverse thrust" for braking only while the gun is actually moving in recoil.)

Because its thrust "follows through" to the end of the counterrecoil stroke, any counterrecoil system tends to drive the recoiling parts into battery with considerable shock. Hence all counterrecoil systems for guns 40-mm and up must have a counterrecoil buffer to take up this terminal shock.

SPRING COUNTERRECOIL SYSTEMS. In all naval guns smaller than 5-inch, coil springs provide counterrecoil thrust. In late 3"/50 mounts and most 40-mm mounts, the springs surround the exterior of the barrel.

HYDROPNEUMATIC COUNTERRECOIL SYSTEMS.—A pneumatic counterrecoil system requires a cylinder or bore (in the housing) charged with inert gas (generally nitrogen or air, never oxygen or other chemically active gas). Gas pressure in a conventional 5-inch system is around 1,500 psi. A plunger (fig. 5-11) fitting into the after end of the housing is forced to the rear by the gas pressure against the after end of the slide. The thrust exerted by the plunger against the slide holds the housing in battery and returns it to battery after firing.

The complication of this arrangement lies in the packing which surrounds the plunger in the housing. Ordinary packing, unsupported, will not withstand the gas pressure in the counterrecoil chamber. Therefore the packing used is a chevron type "inflated" by oil under pressure

(fig. 5-13). The oil pressure in the packing is always higher than that of the gas in the cylinder. The device that ensures this pressure relationship is the differential cylinder. Chapter 3 explains in detail the principle of this device. Gun mount maintenance personnel inspect the cylinder daily, and pump additional oil in if the rod protrudes more than three inches.

Counterrecoil buffers are dashpot devices used to control the velocity and cushion the impact of counterrecoiling parts at the end of counterrecoil. In present designs, they are physically located in the recoil mechanisms, and incorporate needle valves which can be adjusted (within limits) to modify the speed of the counterrecoil stroke.

AMMUNITION TRANSPORT EQUIPMENT

The effectiveness of a gun as a weapon depends, other things being equal, on the number of rounds per minute it can put on target. This in turn depends on the efficiency of the personnel and equipment responsible for transporting the ammunition from its stowage spaces to the mount and feeding it to the gun.

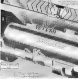

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Figure 5-15.—Hydropneumatic counterrecoil system. Detail of oil-pressure type chevron packing.

Figure 5-14 shows in cutaway form the ammunition transport arrangements for a 5-inch twin mount. At the lowest level is the magazine, in which are stacked the propelling charges. The magazine partly surrounds the lower handling room, which is separated by a flameproof bulkhead from the magazine. Powder cases stored in the magazines are passed by hand through scuttles in the magazine bulkhead to the lower handling room. (Projectiles are normally stored in the lower handling room itself, in racks in the upper handling room, and on the gun-house bulkheads.)

The powder cases and projectiles are then loaded into the 2 dredger hoists (1 for each of the 2 guns in the mount) which haul them up to the upper handling room. Each dredger hoist handles both projectiles and powder cases.

On the upper handling room deck are located the upper ends of the 2 dredger hoists, and around the central column in the room are mounted the 2 sets of projectile hoists and powder hoists, 1 projectile hoist and 1 powder hoist for each gun. The handling room crew removes the projectiles and powder cases from the dredger hoists, loads projectiles into the projectile hoist, and loads the powder cases into the powder hoists. Fuze setters in the projectile hoists automatically set the projectile fuze during hoisting.

Most of the propelling charges are stored in the magazine, and most of the projectiles are stored in the lower handling room. To begin ammunition service without delay, a number of complete rounds are maintained in ready racks in the upper handling room. For long periods of sustained fire, however, the entire ammunition supply system must be in action.

All hoists are driven by electric-hydraulic power units.

AMMUNITION FEED EQUIPMENT

Ammunition feeding and loading devices on the gun or at the gun deck level include power rammers, slide-mounted ammunition loading gear, and equipment used to transfer ammunition from ammunition hoists to the gun slide. These vary considerably in design from one type of mount to another.

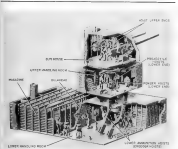

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Figure 5-14.—Ammunition supply system for 5"/38 twin mount.

MISCELLANEOUS SAFETY FEATURES

Some of the safety features of modern gun mounts and turrets have been taken up in connection with the other mechanisms or systems discussed above. But several additional noteworthy ones are briefly discussed below.

SALVO LATCH. This is a device that locks the breech closed. It can be opened only by deliberate effort. Its function is to prevent accidental manual opening of the breech in event of misfire (i.e., an apparently unsuccessful attempt to fire). The reason for this is explained in the safety appendix of this book.

Salvo latches are part of the breech mechanisms of all guns larger than 40-mm, except for automatically loaded guns like the 8-inch case gun used in Salem class turrets.

The salvo latch is a positive lock, cammed to open automatically during recoil. It will not open automatically if the gun does not recoil.

SAFETY LINK.—The safety link is a metal strip that couples the breech yoke (in bag guns) or housing (in case guns) to the slide. (It is

intended to hold the gun in battery in the event of failure of the counterrecoil mechanism, or if the counterrecoil mechanism is disabled. It is used in guns equipped with hydropneumatic counterrecoil systems.

If the gun is fired with the safety link engaged, the link will part. However, it is part of the normal gun operating procedure to disconnect and stow the link before firing. The link must be replaced when the mount is secured.

GAS EJECTOR.—When a shot is fired from a gun, the bore is filled with residual powder gas. The gas is unsafe to breathe, and is likely to be either combustible or actually burning; it is sometimes capable of spontaneous combustion when mixed with air. The gas ejector, which is installed in every enclosed mount 5-inch and larger, forces this residual gas out of the bore by air blast.

When a gas ejector fails, the gun can continue firing, but caution is necessary to ensure safety. The rate of fire may have to be reduced.

SIGHTING AND FIRE CONTROL EQUIPMENT

Getting the gun projectile to hit its target is not as simple as aiming, say, a searchlight beam. A projectile, when fired, travels in a curved path rather than a straight line, and many factors affect the shape of its path. Moreover, since a projectile requires an appreciable time to reach its target, the position of the gun when fired must take into account the distance that the target and the gun will travel with respect to each other during the projectile's flight. To do this requires that all these data be measured and their effects solved mathematically so that the solution indicates how the gun must be positioned for the projectile to hit the target.

The techniques for doing this are called, collectively, fire control. Most of the fire control work is done elsewhere than on the gun mount, but the gun mount does incorporate certain fire control gear—notably the sights. Sights are optical devices which can be used to position the gun with respect to a straight line (the line of sight or LOS) from the gun to the target. Certain more complex sighting equipments (called lead-computing sights) incorporate computing mechanisms which automatically establish gun position with respect to the LOS while a crewman on the gun mount is tracking the target (i.e., keeping the LOS aligned with the target). On-mount fire control gear may also include radar, data receivers and indicators, communication equipment, and auxiliary computing equipment.

TRAIN AND ELEVATION MECHANISMS

In a modern gun mount, the trunnions are placed where the gun is approximately in balance. In conventional designs, handwheels connected through gearing to the training and elevating gear are arranged so that the pointer's handwheels are at his station on the left, and the trainer's at his station on the right. The pointer's handwheels, in gun mounts, turn a pinion which rotates a gear sector on the slide called the elevating arc (fig. 5-15). The trainer's handwheel, through gearing, turns a gear that engages the training circle in the stand.

In turrets using bag ammunition the elevating gear turns an elevating nut which engages a screw pivoted to the gun slide (fig. 5-15 inset). Turrets using case ammunition must be capable of much greater elevations than are practical with this arrangement. They therefore use arc-and-pinion elevating gear.

All turrets, and mounts larger than 20-mm, normally use power drives for positioning the gun. The two main types of power drive are electric-hydraulic and amplidyne electric; the principles of these were described in an earlier chapter.

The conventional arrangements described above in this article do not apply in the newest mounts. For example, in the automatically loaded 3"/50 mounts, the gun cannot be manually elevated and trained from the gun-laying stations on either side of the mount. The controls there provide only for operating the mount through the power drives. The left gun layer's station is used for positioning the mount when firing on air targets; the right gun layer's station is in control for surface targets. Either station, or the director, may be in full control. When either gunlaying station is in control, mount train and elevation are both controlled by that station. Hence there is no "pointer's" station or "trainer's" station on this mount. And manual elevations and train are used only for positioning the mount for maintenance or alignment-checking purposes.

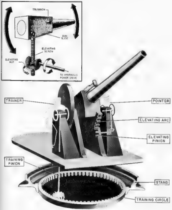

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Figure 5-15. — Training and elevating gear (simplified). (Insert: Screw-type elevating gear.)

GUN BARREL CONSTRUCTION AND MAINTENANCE

Commonly, the term gun applies to the entire assembly of which the barrel is but one part. In this section, gun, tube, or barrel designates the gun tube only, and not the remainder of the gun assembly.

ESSENTIAL REQUIREMENTS OF A GUN

A gun may be considered as a tube designed to withstand a given pressure from within. In constructing such a tube, we must first consider what pressures it will have to withstand at the various points of its length, and then make it strong enough to insure perfect safety. The bore should also be of such material as to stand the wear and tear of firing a large number of rounds without being so damaged by expansion or abrasion as to interfere with the shooting.

STRESSES IN A GUN CYLINDER

Considering a gun only as a cylinder, we find that the two principal stresses (fig. 5-16) to which such a cylinder is subjected upon firing are:

1. A tangential stress or tension, coupled with a radial stress, tending to split the gun open longitudinally.
2. A longitudinal stress tending to pull the gun apart in the direction of its length.

Experiments have shown that the greatest stress on the metal of the gun is the tensile stress set up in the direction of its circumference (tangential stress) by powder gas pressure. In addition, the gun also experiences a longitudinal stress of relatively small value. If this longitudinal stress may be considered constant (and in guns it may be so considered without great error) we may lay down "Lame's law," as follows:

At any point whatever, in a cylinder under fluid pressure, the sum of the tangential tension and the radial pressure varies inversely as the square of the radius.

This law says, in effect, that in a simple hollow cylinder under internal pressure, points in the metal close to the bore experience a large proportion of the stress, whereas those at a greater radius experience only a small proportion. Thus in a simple hollow cylinder of homogeneous metal, we soon reach a limit beyond which any thickness of wall aids but little in enabling the cylinder to withstand pressure.

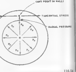

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Figure 5-16.—Tangential and radical stresses in a gun cylinder. Schematic.

Because of this severe limit on the strength of a simple hollow cylinder, however thick, guns must be built on a principle which will enable them to withstand more internal pressure than would be possible with the simple cylinder construction. The problem is to make the outer layers take a proper proportion of the stress.

METHODS OF GUN BARREL CONSTRUCTION

It is possible to make the outer layers of metal in the gun barrel bear a greater share of the load by prestressing the gun tube. There are two types of gun construction using this principle—built-up construction and radially expanded construction.

The "built-up" method of prestressing is to heat steel ring-shaped jackets, or hoops, to high temperatures, then slip them over the gun tube and allow them to cool. As the hoops cool, they contract, until at the end of the process they squeeze the gun tube with a pressure of thousands of pounds per square inch. Guns so constructed have been in recent years made only in sizes over 8-inch.

About the time of World War I, the same principle was applied to monobloc (one-piece) guns in the radial-expansion or autofrettage process. In this process, a gun tube with bore slightly smaller than the caliber desired is expanded by hydraulic pressure. When the pressure is released, the outer layers of the tube tend to return to their original dimensions, while the enlarged inner layers tend to maintain their enlargement. Thus the inner layers of metal are severely compressed by the contraction of the outer layers, as if a hoop had been shrunk on.

The built-up and radially expanded methods may be incorporated in a single gun. The 8"/55 caliber gun, for example, has a jacket shrunk on a radially expanded tube.

Smaller guns are made from a single steel forging with neither radial expansion nor hoops. The pressures in small guns may be higher than in large guns, but the forging, which is not excessively large in any event, can be made bigger. This type of construction is, at the present time, limited to guns of 3-inch caliber and smaller.

DETERIORATION IN THE GUN BORE

The "working surfaces" of the gun are the interior of its bore and chamber. As time passes, and as round after round is fired, these surfaces will deteriorate, and maintenance is required to ensure their continued usefulness. The main causes of deterioration are (1) erosion, (2) corrosion and dirt, (3) copper fouling, and (4) constriction.

Erosion

Erosion is the deterioration and wearing away of the bore surface caused by firing projectiles through it. Erosion is not merely the direct effect of friction which causes the bore surface to wear away as the projectile passes through. The exact mechanics of erosion are not known with precision, but the following are recognized as the principal causes:

1. The bore surface becomes intensely heated in firing, and the rush of hot gases across this hot metal has a scouring effect.

2. The hot powder gases react with the metal, changing the carbon content on the surface of the bore. Since this surface is designed with an optimum carbon content, any change results in a weakening of the metal.

3. The alternation of intense heat and rapid cooling affects the temper of the metal.

4. The propellent gases are forced into and out of the pores in the metal surface as they open and close during the expansion and contraction which accompanies such drastic temperature changes.

5. Heat cracks may develop.

6. Gases escaping around the projectile act as high-velocity jets, scouring the bore and causing damage, especially where there are heat cracks.

Erosion is always greatest at the origin of rifling (fig. 5-17) and the tops of the lands wear away faster than do the bottoms of the grooves.

Erosion at the origin of rifling, in guns using semifixed ammunition, tends to permit the projectile to seat farther and farther toward the muzzle. This reduces the density of loading (density of loading is explained later in this chapter) and therefore the I.V. (initial velocity). In guns using fixed ammunition, this effect does not apply, but in all guns erosion at the origin of rifling permits gas to escape around the projectile, and this in turn increases erosion.

As the lands wear, not only does more gas escape around the projectile but the rifling engraves the band less deeply, reducing materially both the initial forcing pressure and the resistance of the projectile to the gas pressure. The effect is a material drop in muzzle velocity.

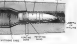

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Figure 5-17.—Erosion areas in a gun chamber and bore.

CONTROL OF EROSION.—All erosion factors are related to (1) the temperature of the expanding gases and (2) the duration of their confinement in the bore. Hence larger guns, with their slower powders and longer barrels, suffer more erosion per round firing than smaller guns. On the other hand, smaller guns have a higher firing rate, which permits less cooling time between rounds.

Chromium plating of gun bores has reduced the effects of erosion; the use of molybdenum will probably make for even better erosion resistance in the future.

Some smaller guns are cooled by water jackets around the barrels, and there have been experiments on introducing a coolant between the tubes and the liners of larger guns. Also under development are cooler propellants. Any development that reduces the heat of explosion will aid in erosion control.

There are, for each class of gun, data sheets furnished to ships showing relationship between the enlargement of the bore and the initial velocity to be expected from the gun. The data sheets show this information in the form of plotted curves. If the actual diameter is frequently checked, velocity loss becomes predictable, proper allowance for it can be made in aiming, and barrels or liners may be replaced before their performance becomes noticeably erratic.

In some minor-caliber guns, measurements of bore enlargement is made at the origin of rifling only. This is done with a wear gage, which is a truncated cone that can be inserted directly in the breech. In larger guns, erosion is measured at several points in the bore with a star gage.

The star gage (fig. 5-18) consists of a head mounted on a long tube, with metal points 120° apart extending radially from it. These three points form a Y and press against the bore of the gun. Points of suitable length are provided for each caliber of gun to be measured. The bases of the points are spring-loaded to bear against a tapered expanding plunger; as the plunger (operated by the vernier lever) moves longthwise, the points are cammed outward or inward. Measurements are read from the vernier scale.

Stargaging is performed by highly skilled personnel in tender or shore-based facilities. The object is to measure the amount of erosion along the bore (and especially its origin) so that the corresponding predicted loss in I.V. can be included in the solution of the fire control problem. Tables, charts, graphs, and equations are provided in OP 551 (latest revision) for use in converting erosion losses into usable I.V. information. Although this particular OP is for a 5"/38, there is a similar publication for each type of gun.

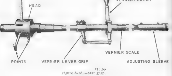

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Figure 5-18.—Star gage.

Obviously, since stargaging is done in port, and ships are usually at sea, a stopgap is necessary to compute the correct I.V. The stopgap is called EQUIVALENT SERVICE ROUNDS (E.S.R.). Immediately upon receipt of stargage data, the ship converts these data into an E.S.R. for each gun so gaged. The gun E.S.R.s for a battery are then averaged, the applicable OP is consulted for conversion factors, and the resultant I.V. is set into the computer which serves the battery. This is a usable I.V. only as long as no rounds are fired from the battery. As soon as more rounds are fired another quantity must be added to the I.V. computation. That quantity is called PSEUDO EQUIVALENT SERVICE ROUNDS (P.E.S.R.). P.E.S.R. comes from estimates which are based on the fact that each round fired causes a certain amount of erosion. Projectiles which are propelled by full-service powder charges are counted as one P.E.S.R., while reduced-charge firing may be equivalent to about 1/6 of a P.E.S.R. per round fired. (The Navy uses reduced charges for reverse-slope firing.) P.E.S.R. is added to E.S.R. for I.V. computation, but kept separately in records so that comparison can be made with the E.S.R. from the next stargaging. That is, was the P.E.S.R. an accurate estimate of the actual erosion?

Without periodic stargaging, the E.S.R. procedure would not be accurate, mainly because the P.E.S.R. quantity does not reflect the rate of fire. Rounds fired with very short cooling intervals cause more erosion than the same number fired at a normal rate. For practical gunnery, however, this method is considered sufficiently reliable for use.

I.V. MEASUREMENT.—At proving grounds gun projectile velocity is measured by a device called a chronograph. The projectile cuts wires when it passes through two successive screens, or it passes through two magnetic coils, and the exact time of each passage is recorded. This yields the projectile velocity between the screens, and from this I.V. can be reckoned.

Chronographs require special setups of coils or screens, careful gun placement and aim, much auxiliary equipment, specially skilled technicians, and a good deal of time. They are consequently not practical for shipboard use. But because erosion and I.V. are significant factors in fire control, the Navy has developed devices on far different principles which can actually measure the velocities of service rounds fired on shipboard. These velocity-measuring devices are incorporated in some gun fire control systems.

Corrosion and Dirt

Great heat, great pressure, and complicated chemical changes accompany the burning of the propelling charge. Some but not all the residue of the burning is blown out of the muzzle after the projectile. What remains in the gun (powder fouling) is in the form of corrosive salts. Standard procedure is to remove it by washing out the bore with a hot soda solution and applying a thin film of oil before securing until the next firing. Chromium plating of gun bores has reduced the powder fouling problem.

Dirt in a gun bore not only encourages corrosion but is a source of danger if it offers sufficient resistance to the projectile. To guard against accidental admission of dirt, spray, or moisture into the gun, a solid plug called a tompion (pronounced tom-kin), is inserted into the muzzle. This is only a partial solution, because under certain weather conditions considerable condensation accumulates in the bore. In fair, dry weather, tompions are removed to air out the barrels.

Tompions cannot be used under combat conditions; a tompion accidentally left in a gun would be very dangerous if the gun were fired. However, dirt and water, especially salt water, must be kept out of the gun; so canvas or plastic muzzle covers are used. In an emergency, the projectile can be fired through such covers without bursting the barrel, subject to certain limitations. Projectiles with supersensitive nose fuzes cannot be fired through muzzle covers of any sort. In cold-weather operations, when canvas covers may become ice coated, they should be removed before firing.

Constriction

More immediately dangerous than corrosion or dirt is metallic constriction of the bore. Before and after each firing, barrels are tested for this condition with a plug gage, which is a steel cylinder accurately machined to slightly under the diameter of the bore (fig. 5-19). If the plug gage will not pass through the bore without undue forcing, the nature of the constriction must be determined. If it is caused by an accumulation of copper, it is dealt with as described in the next topic. This is the more likely cause. However, constriction can also be caused by distortion of the steel surface of the

110.56
Figure 5-19.—Plug gage (left) and lapping head.

bore. This has been known to occur in built-up guns. The friction of the projectile on the bore tends to drag the liner along with it. This tendency is resisted by the shoulders of the liner and the tube. With continued firing, the shoulders of the liner tend to override those of the tube, forcing the walls of the liner inward. As with coppering, steel constriction can be removed by lapping and polishing.

Continued firing may also elongate the liner and cause it to protrude from the muzzle. This is not serious. When the extension amounts to as much as half an inch, it is simply cut off.

Copper Fouling

Copper fouling is essentially a form of constriction. It consists of metallic deposits on the bore, left behind by the rotating bands of projectiles. Even an amount of copper too slight to impede the projectile will affect its accuracy. Metallic lead foil in the powder charge, while increasing muzzle flash, has been used in some powders to control coppering. The lead serves as a lubricant and discourages new copper deposits, while existing deposits will be abraded by the passing projectile. New propellants incorporate a trace of lead carbonate.

Copper fouling may be removed with an acid treatment, but this is not authorized for shipboard use. Approved mechanical means for decoppering consist of rubbing with a wire bore brush or lapping head (fig. 5-19). The head is covered with a fine abrasive material and is drawn back and forth at the location of the constriction until the plug gage can be passed through without forcing. Special scraping or decoppering heads, fitted with steel blades, are supplied for certain guns.

3"/50 RAPID-FIRE GUNS AND MOUNTS

The 3"/50 rapid-fire (RF) guns are semiautomatic guns with automatic power-driven loaders, installed in open or enclosed twin or single mounts. They are primarily intended for air defense, but can be used against surface targets. They were planned during World War II when a need developed for a rapid-fire gun with a larger explosive-projectile that could stop suicide planes or dive bombers. The 3"/50 mount was not completed in time to be used in combat in World War II, but it has since proved itself very effective, and since World War II has virtually displaced its predecessors—40-mm twin and quadruple mounts—on combat vessels. It is generally used with relative-rate fire control systems.

The 3"/50 rapid-fire mounts now operational in the fleet are the outwardly identical twins Mk 27 and mods and Mk 33 and mods (fig. 5-20), and the single Mk 34. All use the same gun and similar loading mechanisms (except that in the twin mount the assemblies are of opposite hand). The two marks of twins are similar in nearly all details except the slide.

Two mods of the Mk 33 are enclosed twin mounts with aluminum shield. The other mods are open twins with modifications for installation of a fire control radar antenna, or for substitution of aluminum platforms instead of steel. The Mk 34 mount is an open or enclosed single, similar in controls and equipment to the twin, with a right-hand slide and loader assembly.

General Characteristics of 3"/50 RF Mounts

Bore caliber (inches)	3.
Length (calibers)	50.
Initial velocity (feet per second)	2,700.
Range, horizontal (yards)	14,200.
Range, ceiling (feet in 85° elev.)	30,400.
Design rate of fire (rounds per minute)	45.
Ammunition type	Fixed, electric primed.
Fuze type	VT.

*Approximate weight, complete mount (pounds).

Mk 27	31,000.
Mk 33	31,000.
Mk 34	17,000.
Train rate (degrees/second)	30.
Elevation rate (degrees/second)	24.
Maximum elevation (degrees)	85.
Maximum train (degrees)	720.

*Not counting off-mount equipment.

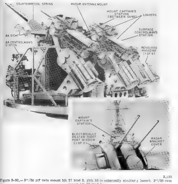

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Figure 5-20.—3"/50 RF twin mount Mk 27 Mod 3. (Mk 33 is externally similar.) Insert: 3"/50 twin mount Mk 33 Mod 4.

CONSTRUCTION

The barrel of the 3"/50 gun is a one-piece, rifled, chambered tube, with breech end locked to the housing by a bayonet type joint. The housing contains the vertical sliding-wedge breech mechanism. The slide supports the recoiling parts (gun barrel and housing) on bearings. Recoil and counterrecoil movement are controlled by a hydraulic recoil cylinder and a large counterrecoil spring surrounding the barrel.

The slide, gun, and housing are supported by the carriage. The slide trunnions rest in roller bearings at the top of the carriage. The elevating arc on the slide meshes with the elevating pinion of the mount elevation power drive system.

The stand is a deck-flange, base-ring design which includes the training circle and the stationary roller path. In train, the mount is driven by a power motor which rotates the training pinion.

BREECH MECHANISM

In OP language, the 3"/50 breech mechanism is "an automatic, vertically sliding, block type which is unlocked during gun recoil action and is opened downward by gun counterrecoil energy. Its opening action extracts the empty cartridge case and sets a mechanism that holds the breech against the load of a breech closing spring. Ramming a fresh round releases these devices to automatically close the breech."

The breechblock is cammed by operating shaft rotation, as in the 5"/38. In automatic operation the breechblock is lowered and the operating spring compressed on counterrecoil when the operating-shaft crank is rotated by the operating-shaft cam plate in the slide. The breech is closed by the operating spring. The positive type salvo latch on one end of the operating shaft prevents unintentional opening of the loaded breech before the gun has fired. The breechblock houses a firing mechanism.

The general principles of sliding-wedge breech mechanism construction and operation described later in the section on 5"/38 mounts apply to the 3"/50 gun, but two design features peculiar to the 3"/50 deserve some brief but close examination. These features are:

1. A BREECHBLOCK HOLD-DOWN MECHANISM holds the breech open until the loader completes delivery of a round, and, with a novel extractor arrangement, increases the sensitivity of the breechblock-unlocking action.
2. A BREECH INTERLOCK MECHANISM prevents repetition of the loading cycle until the round has been fired and the breechblock dropped.

As you remember from earlier studies, ammunition is fed into the chambers of most naval guns by ramming—by a mechanically delivered push that "follows through" until the projectile is seated. In contrast, each gun on a 3"/50 mount is equipped with a mechanical loader (to be described later in this section) which catapults each round into the chamber. Since there is no follow-through, the breech mechanism must be "triggered" into closing by the momentum of the catapulted round as it is thrown forward by the loader at about 9.5 feet per second. This triggering function is performed by the hold-down mechanism, shown in figure 5-21. The hold-down lever is pivoted near its center. When the gun is in battery and the breechblock is held down, the hold-down lever bears on the hold-down arm of the breech operating shaft to prevent rotation of the shaft and closing of the breech. The hold-down latch lever interlocks the breech mechanism with the loader, unlocking the hold-down device when a new round is to be catapulted into the breech. The hold-down mechanism when unlocked will allow the breechblock to rise (to breechclosed position) when the rim of a catapulted cartridge case trips one of the extractors, which operates a push rod to trigger the mechanism.

The breech interlock mechanism, which is technically a part of the loader, is a system of mechanical linkages which functions automatically to stop the loader from delivering another round to the breech whenever there is a round in the bore or the breechblock is up, or the gun is out of battery. When either a round is rammed or the block is raised, it actuates the loader control lever to prevent the start of a new loading cycle.

LOADER

The loader (figs. 5-20 and 5-22) is an independent, electric power-driven machine mounted on the after part of the slide. It mechanically loads each gun at the rate of 40 rounds per minute as long as ammunition is served and the firing control is operated. It is bolted to the after end of the gun slide, and is fed manually by two crewmen, who insert the fixed ammunition one round at a time into the feed sprocket on each side (fig. 5-22A). The outer sprockets alternately shift the rounds to the center sprocket, which centers the round to be loaded above a gate mechanism. When the breech is open, the gates admit the round to be loaded to a shell carriage mounted on a tray which is parallel to the gun bore axis. The loaded tray swings down on its four arms until it is aligned with the chamber, then the shell carriage, driven by an electric motor, catapults the round into the breech (fig. 5-22B). After the round clears the carriage, the tray swings upward into position to accept another round.

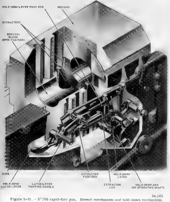

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Figure 5-21. — 3"/50 rapid-fire gun. Breech mechanism and hold-down mechanism.

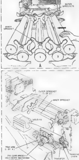

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Figure 5-22.—3"/50 loader. A. Sprockets being loaded. (Center sprocket alternates direction of rotation each cycle. Rounds numbered in sequence of loading.) B. Cartridge being catapulted into breech housing.

The breech interlock automatically blocks repetition of the loader operating cycle until the gun has fired, recoiled, and returned to battery with breech open for the next round.

All these functions are mechanically timed by control devices in the loader drive unit, and all are sequentially interlocked.

GUN OPERATING CYCLE

Here, briefly, are the main steps in the cycle of operation of the 3"/50 gun and loader.

1. Crewmen load rounds into the hopper of the loader (fig. 5-22A). Three cycles of loader operation are necessary before the loader is ready to catapult the first round of ammunition into the breech, which it does on the fourth cycle.

2. As the tray approaches the bottom of its swing (fig. 5-22B), the shell carriage moves forward to catapult the round into the gun breech. At the same time, a pin on the tray cams a lever on the breech hold-down device to unlock it.

3. As the round flies forward into the breech, the cartridge rim engages the extractors. Extractor movement releases the unlocked hold-down device (see preceding step) and the operating spring raises the breechblock to close the breech. The breech interlock and several electrical interlocks keep the loader from recycling until the proper time.

4. As the breech closes fully, the firing pin contacts the cartridge primer much the same as in the 5"/38 mechanism. When the firing circuit closes, the gun fires, recoils, and counterrecoils.

5. As the gun counterrecoils, a breech opening cam on the slide engages the operating shaft crank. This rotates the breech operating shaft, pulling the breechblock down until the hold-down device locks it open. The extractors (not shown) haul the fired case out while the block goes down. The gun is now ready for the loader to catapult the next round.

MOUNT DRIVES, CONTROLS, SIGHTS, AND CREW

All 3"/50 rapid-fire mounts have amplidyne power drives for both train and elevation.

There are no provisions for manual drive, except handcrank arrangements (not illustrated) intended only for stowing and servicing the

mount. But there are two types of local control—AA LOCAL and SURFACE LOCAL, plus automatic remote control from a director. Each side of the mount has a separate control station.

In AA local, the left gun layer (AA operator) controls the mount in both train and elevation, and fires the mount. The left gun layer uses a ring sight (fig. 5-23A) and a one-man gun-laying control unit with firing key. The right gun layer's controls (part B) consist of a telescope and open sight, and a one-man gun-laying control unit with firing key. Handwheels are not used in local control for positioning the mount; the gun layers train the mount by rotating the control units about a vertical axis, and elevate by rotating the control handles about a horizontal axis. However, automatic control (with the gun layers merely standing by) is the preferred type of control.

The surface sight is a combination open sight and telescopic unit with provision for sight setting. With the AA sight, it is mounted on a yoke astride the slide. The surface gun layer uses the open sight to get the target into the comparatively restricted field of view of the telescope. Then he shifts to the scope, adjusting mount position with his controls to keep the crosshairs on the target. A sightsetter can crank in deflection and sight angle values in accordance with telephoned orders. There are no synchros transmitting these values to the sight setting mechanism (not illustrated).

In addition to the AA and surface gun layers and sightsetter already mentioned, the 3"/50 RF mount crew includes a mount captain, four shellmen, and four shell passers (fig. 5-24). The mount captain is the supervising gunner and crew captain. His operations are directed by phone by the control officer. He controls both guns with the mount captain's controls. His controls allow him to select the control station, switch to single or automatic fire, select the gun or guns to fire, and control the loaders. He also has power-drive emergency stop buttons and two banks of neon indicators to enable him to check the loader. His firing key must be closed before the loaders will function. It can be latched closed when control of fire is to be at either left or right control station or at the director.

Two shellmen for each gun load ammunition into the hoppers of the loaders. Shell passers keep the shellmen supplied.

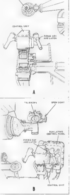

Figure 5-23.—3"/50 mount. A. Left (AA) gun layer's station. B. Right surface gun layer's station. 110.89

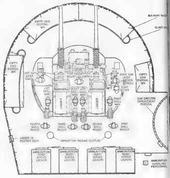

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Figure 5-24.—3"/50 rapid-fire twin mount. Crew stations.

5"/38 GUNS AND MOUNTS

The 5"/38 gun is one of the most widespread naval weapons in the fleet today. It is not a new design, but its reliability and the essential soundness of its design have continued its usefulness into a day when it is far outranged by spectular new weapons. Many of its design features persist in the very newest gun designs in the fleet, but on the whole it can be considered the prototype of the "conventional U.S. naval gun." It is the weapon characteristically used with linear-rate fire control systems.

The 5''/38 gun appears in the following general types of mounts:

1. Enclosed twin mount with ammunition-handling room beneath the mount. The type of mounts is a standard installation on many cruisers, and destroyers, and some aircraft carriers.

2. Enclosed single mount with ammunition-handling room beneath the mount. This is the old standard destroyer-type mount. It is now found on many minecraft and auxiliaries developed from the older classes of destroyers, on destroyer escorts, and on many large auxiliaries (repair ships, destroyer tenders, etc.).

3. Open single mount with ammunition-handling room beneath the mount. This mount is used on auxiliary ships.

4. Open single mount without ammunition hoists or handling room. Because mounts of this type can be installed without extensive reconstruction, it is used on converted merchant vessels.

Another mount similar in design to the 5''/38 is the 5''/54 (Mk 39), which is used on Midway class aircraft carriers. It has a longer barrel and an amplidyne all-electric power drive in contrast to the electric-hydraulic power drive used in all 5''/38 mounts. Do not confuse this mount with the automatic-loading 5''/54 (MK 42) which is covered later.

GENERAL DESCRIPTION OF 5''/38 MOUNTS

The 5''/38 caliber gun is a semiautomatic, dual purpose, base-ring-mounted gun which uses semifixed ammunition. Its principal features are:

1. Vertical sliding-wedge breech mechanism.
2. Hydraulic recoil and hydropneumatic counterrecoil systems.
3. Power-operated rammer.
4. Power-operated elevating and training gear.
5. Movable-prism telescopes.
6. Power-operated fuze-setting projectile hoist.
7. Power-operated powder hoist on all twin mounts and some singles.

The 5''/38 mount uses semifixed ammunition consisting of a 54-pound projectile (weight varies somewhat with type of projectile) and a case assembly weighing about 28 pounds, which includes a 15-pound powder charge. Ballistic performance obtained with a 15-pound service charge (full charge) is as follows: initial velocity, 2600 feet per second; maximum horizontal range, 18,000 yards; maximum vertical range, 37,300 feet. (the Mk 39 5''/54 uses heavier ammunition and has longer ranges.) The gun is capable of sustained firing at a rate well in excess of any which can be attained by the loading crew. An experienced crew can load about 15 rounds per minute for long periods, and may attain a short-period rate of 22 rounds per minute.

The gun has a radially expanded 2-ton steel monobloc barrel. The rifling has a uniform twist of 1 turn in 30 calibers. The bore is chromium plated from the forward portion of the powder chamber to the muzzle. The barrel is connected to the housing by a bayonet-type joint.

The housing (fig. 5-25) is a rectangular block-shaped forging, with forward portion machined to receive the barrel. In the center is a vertical well for the breechblock; and to its rear is a trough-like ammunition-loading tray. The housing contains twin interconnected recoil cylinders (groove type) and a single counterrecoil cylinder. The housing supports and locks the gun in the slide, and moves on the slide guides during recoil and counterrecoil.

The slide (fig. 5-26) is a large box-shaped weldment, open at top and bottom, within which the housing moves in recoil and counterrecoil. The housing is supported and guided by two guide rails bolted to the inner side plates. The elevating arc and the rammer are secured to the slide. Other mount structure details resemble those of conventional practice described earlier.

All enclosed mounts are housed in a shield of armor plate. The shield is a box-like structure that provides weather, blast, and splinter protection for the crew.

Through doors on both sides near the after end, the operating personnel enter or leave the mount. Other doors and access cover plates provide for inspection and repair. A roof hatch may be located near the after end of the gun mount. Where necessary, this hatch has a blast hood. Sight hoods on the side shield plates protect the three sight telescopes. A ventilation system supplies air to the mount and handling room.

Lights in the gun and handling room are energized by the ship's general illumination circuit, which also includes outlets for battle lanterns, window-wiper motors on each sight telescope, and the battle illumination system,

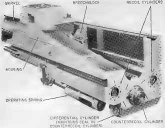

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Figure 5-25. — 5-inch housing and gun (removed from slide).

which energizes small lamps at all instruments and controls.

Gun elevation, gun train, fuze setting, and sight setting synchro signals are supplied to the indicator-regulators and the sightsetter's indicator in the mount by fire control circuits from the computer.

Communication facilities in 5"/38 mounts may include (1) a voice tube between gun room and upper handling room, (2) an automatic telephone in the ship's general communications system, (3) a sound-powered battle phone circuit between mount and fire control stations, (4) an auxiliary sound-powered phone circuit with call bell between mount and lower ammunition-handling room, and (5) a loudspeaker connected to the director and plotting room.

BREECH MECHANISM

The important parts and the operating cycle of the 5"/38 breech mechanism are shown in figures 5-27 and 5-28. In operating principles and general construction the mechanism is similar to that of the 3"/50, and in lesser degree though still to a significant extent it resembles the breech mechanisms of the rapid-fire 5"/54 Mk 42.

The breechblock is a steel block which can slide up and down on guides in a breechway in the

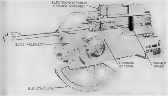

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Figure 5-26.—5-inch slide removed from mount and minus gun and housing.

84.150
Figure 5-27.—5-inch breech mechanism parts, breech closed.

housing. It is positioned by an operating shaft in the housing. The thrust of a coil spring as exerted through a chain on the shaft tends to drive the block upward to closed position. The salvo latch on one end of the crank locks the mechanism in breech-closed (breechblock-up) position; it is unlocked either by a cam on the slide or manually (if necessary). The block is forced down to breech-open position during counterrecoil by another cam on the slide which engages the lug on the crank during counterrecoil. The block is locked down by a pair of extractors, one on each side of the block. A hand-operating mechanism (not illustrated) provides for manual operation of the breech mechanism. The breech must always be opened by hand to start firing; hand operation is also required in maintenance operations, and when mechanical failure makes semiautomatic operation impossible.

Now follow the breech mechanism operating cycle. (Some details are omitted for the sake of clarity.)

1. (Figure 5-28A.) We start with breech open. Rammer (only the spade, which actually

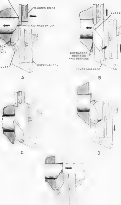

Figure 5-25. — 5-inch breech mechanism operating cycle. 84.1

pushes the round, is shown in the figure) thrusts round into chamber. Rim of case engages extractor lips and pushes them forward, unlocking block.

2. (Figure 5-28B.) Driven by breech-operating spring, block rises, wedging cartridge case into chamber. When breech is fully closed, salvo latch locks it closed. (Figure 5-27 shows salvo latch locking mechanism in closed position.)

3. (Figure 5-28C.) Gun ready to fire. It fires and recoils, but this diagram requires no change. However, salvo latch is cammed (not shown) to unlock breech (not to open it) during recoil.

4. (Figure 5-28D.) The gun counterrecoils. Cam (not illustrated) on slide engages crank lug on operating shaft and rotates shaft, causing it to lower breechblock. As breechblock drops, extractors begin to rock rearward. Extractor lips still engage cartridge case rim, hence case is forced out of chamber.

5. (Figure 5-28E.) Breechblock drops further, causing extractors to flip case out to the rear. When block is fully down, extractors remain in rearmost position and lock block down.

FIRING SYSTEM

The firing system of a 5"/38 mount closely follows conventional practice as described earlier. There is a firing mechanism in the breechblock; its insulated firing pin is in contact with the cartridge primer only when the gun is loaded, the breechblock is closed, and the gun is in battery. A foot-firing mechanism permits firing the primer by percussion, but this is rarely done. The standard method is to use the firing circuit. The pointer has a key which closes the secondary circuit of the firing transformer; the mount captain has a switch to permit selection of local or remote firing. In remote-control firing, the pointer's key is closed, and firing is controlled from either the director or plot.

The firing stop mechanism keeps the firing circuit open and the percussion firing linkage disconnected unless the gun is on an elevation and bearing at which the projectile will not hit the ship's structure.

GAS EJECTOR SYSTEM

Gas ejectors prevent entry of powder gases into gun mounts, safeguard against the danger of flarebacks, and assist in maintaining a rapid rate of fire by clearing the bore of gases. Air under pressure of approximately 75 pounds per square inch is piped from the ship's supply to nozzles in the breechblock guideways pointed toward the gun bore. During counterrecoil, a gas ejector valve in the housing is cammed open and gas ejection begins. The valve is closed by the rammer as the next round is rammed. A hand lever permits manual opening and closing of the valve.

RAMMER AND AMMUNITION HANDLING CYCLE

The rammer is a semiautomatic electric-hydraulic unit on the upper rear part of the slide. A 7 1/2-hp electric motor drives a pump whose output is controlled by valves to operate the ram cylinder. The piston of the cylinder is mechanically linked to a rubber-faced rammer spade which moves forward along the loading tray, and to the rear in an elevated path along the slide. The cycle of operation is as follows:

1. Two crewmen (the projectileman and powderman) take the projectile and powder case out of their hoists and deposit them in the loading tray in the slide.

2. The rammerman depresses a control handle (fig. 5-29A). The ram cylinder forces the rammer spade forward (arrow (1)) to ram the round into the chamber.

3. When the breechblock closes and the gun fires and recoils (arrow (2) in fig. 5-29, part B), the rammer spade is automatically retracted (arrow (3)) along an upper path in the slide. This lifts the spade so that it will not obstruct the extracted cartridge case's path (arrow (4), fig. 5-29C) to the rear. A crewman throws the fired case out of the mount in single mounts. In twin mounts, except when gun elevation exceeds about 30°, case ejection is automatic.

4. The gun captain prepares for the next round by lowering the rammer spade to ram position.

TRAINING AND ELEVATING GEAR AND POWER DRIVES

The general principles of training and elevating gear were explained earlier in this chapter, and those of power drives in chapter 3. Those of 5"/38 mounts exemplify these principles in conventional applications, and will not be described in further detail here.

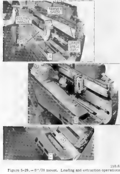

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Figure 5-29. — 5"/38 mount. Loading and extraction operations.

HOISTS

In the ammunition transport installation for a twin 5"/38 mount, powder cartridges are manually loaded into dredger hoists, which lifts them to the upper handling room. Here they are manually removed from their tanks and transferred to a powder hoist which lifts them to the gun house. In the gun house a crewman manually transfers them from powder hoist to gun slide.

Projectiles typically are handled similarly, except that they are not stowed in tanks.

The powder and projectile hoists between the upper handling room and the gun house are quite different in functioning. The powder hoist (and dredger hoists are similar in principle) consists fundamentally of an articulated endless chain with supports or flights secured to it at regular intervals (fig. 5-30A). Powder cases are loaded by pushing them into the hoist in the path of

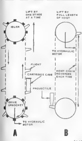

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Figure 5-30.—Principles of 5"/38 hoists. A. Powder hoist. B. Projectile hoist. (Fuze setter not shown.)

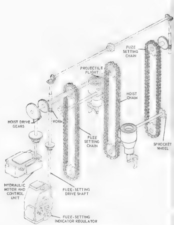
the flights; when the hoist starts, the chain is driven upward until the next vacant flight is in loading position. When the next unit is loaded, the hoist goes up one more flight, and so on. The hoist starts automatically when loaded, except instances when a round is at the top of the hoist. The hoist is driven by a rotary hydraulic motor whose functioning is controlled by valves.

Endless-chain hoists generally can be operated in reverse to lower ammunition units, as is required in taking ammunition aboard. In either mode of operation, the hoist moves one flight at a time, intermittently in the same direction. Only one side of the chain is used.

The projectile hoist, in contrast, has an endless chain in which both sides of the chain are used (fig. 5-30B). There are 2 flights, arranged so that when one is at the top of the hoist on one side, the other is at the bottom of the hoist on the other. The chain runs first in one direction, then the other, and the flights always move from all the way at the top to all the way at the bottom (or vice versa), as in the old-time well with 2 oaken buckets, one of which descended while the other went up. The projectile is loaded into one side, and automatically the hoist starts if the top is empty. As the loaded flight ascends, the empty comes down. The cycle reverses for the next projectile.

In addition to hoisting projectiles (it is never used for lowering them), the 5-inch projectile hoist also sets the projectile fuze (when a projectile with time fuze is loaded). As you can see in figure 5-31, the projectile hoist has three chains. The center one is the hoist chain. It is driven by a hydraulic motor through shafting that rotates a sprocket at the top of the chain. Each of the other two chains is part of the fuze setting linkage. They are positioned by the fuze setter indicator-regulator, a servomechanism controlled by the fire control computer. Each projectile flight has a small sprocket wheel which engages one of the chains. As the projectile flight is hoisted by the hoist chain, its wheel "walks" up the fuze setting chain. This rotates a ring (not shown) inside the flight. The projectile is manually loaded nose down into the flight. If it is a time-fuzed projectile, it is loaded so that a lug on the fuze engages the ring in the flight. As the projectile is hoisted, the fuze's lug is rotated by the ring. This adjusts the fuze to the desired time setting. So long as the projectile remains in the hoist, the time fuze setting is continuously adjusted by the fuze setting indicator-regulator through the fuze setting chain and ring. The time lapse from the instant the projectile is removed from the hoist (after which its fuze adjustment ceases) until it is fired is called dead time, which is estimated and included in the fire control computation.

This discussion of ammunition supply equipment has concentrated on twin mounts, which are the most elaborately equipped. Some single 5-inch mounts (for example, the single 5"/54 Mk 39 mount) are equipped with one powder hoist and one projectile hoist per mount. Other single 5"/38 mounts may have only a projectile hoist, plus (instead of a powder hoist) a deck scuttle through which powder cases are pushed by hand. Some auxiliaries are still equipped with open mounts with similar arrangements, or with no



110.63

Figure 6-31.—5-inch projectile hoist. (Schematic.)

boats at all, but this is not the normal condition aboard combat vessels in the active fleet.

SIGHTS

All enclosed 5-inch mounts, both twin and single, are fitted with carriage-mounted telescopic sights in which movable prisms in the optical system provide for offsetting the gun bore axis from the line of sight (LOS). All twin mounts have three sights—one for the pointer, one for the trainer, and one for a sight checker. However, there are but two optical systems—one for the trainer, and one that is shared by the pointer and checker. Each optical system has two movable prisms—one to introduce deflection, the other to introduce sight angle. The sighting system also includes a sightsetter's indicator operated by the sightsetter. These units and the mechanical linkages between them are shown in figure 5-32, which depicts the front of a twin mount with the shield removed.

The sightsetter's indicator is shown in figure 5-33. It has a sight deflection handcrank, a sight angle handcrank, and three sets of dials—a pair of deflection dials (one coarse, one fine), a pair of sight angle dials (one coarse, one fine), and a range dial. The indicator receives sight deflection and sight angle synchro signals from the computer. The deflection dials are calibrated in mils (6400 to the circle), with the zero point arbitrarily chosen as 500 mils on the dials. Sight angle dials are calibrated in minutes (21,600 to the circle) with the zero point (gun bore axis parallel to LOS in a horizontal plane) arbitrarily chosen at 2000 minutes. (Using these arbitrary values instead of zero eliminates the need for using signs to indicate the direction of offset.)

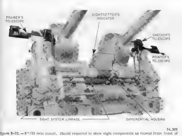


Figure 5-32.—5"/38 twin mount. Shield removed to show sight components as viewed from front of mount.

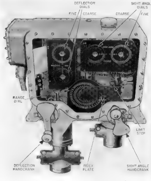


Figure 5-33.—5"/38 twin mount. Sightsetter's indicator.

The range dial, which is geared to the sight angle handcrank, is calibrated in yards, and is used in emergencies against surface targets when no sight angle data are available from fire control plot.

MOUNT CREW

Figure 5-34 shows the crew stations of a single 5"/38 mount. The duties of the mount crew are described below.

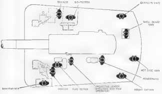


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Figure 5-34.—5"/38 single mount, crew stations (gunhouse).

The mount captain is the command leader. If available a gunner's mate is his principal assistant and supervisor of gun operation. He serves as troubleshooter and chief maintenance man. The pointer is responsible for checking and operating his sight and when not in automatic the elevating gear; he also, in most cases, fires the gun. The trainer does similarly for his part of the mount except for firing the gun. The sightsetter receives and sets sight deflection and sight angle. The fuze setter tests the fuze-setting mechanism, and operates it when the fuze setter is not in automatic. The projectile-and-rammerman operates the rammer and loads projectiles. The gun captain lowers the rammer spade and checks the loading operation. The powderman takes the cases out of hoist and passes them to the loader-hot-case man, who puts the cases in the slide.

In addition to these ten men in the gun house, there are six in the upper handling room (not diagrammed). Two powdermen keep the powder hoist supplied, two projectilemen do the same for the projectile hoists, and two others operate scuttles through which ammunition is passed from the magazines.

In a twin mount many of these crew stations are duplicated because there are two guns and two sets of hoists. The crew totals 27.

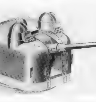
5"/54 GUN MOUNT

With the coming jet aircraft, it has been necessary to develop a reliable antiaircraft gun with increased range, tracking rate, and firing rate. The rapid-fire 5"/54 gun mount not only satisfies these requirements, but it is quite effective against surface and shore targets as well.

The following discussion is concerned with the 5"/54 Mk 42 and, briefly, the Mk 45 gun mounts.

5"/54 Mk 42

The 5-inch mount Mk 42 (fig. 5-35) is a shielded, dual-purpose, single-gun mount with an automatic firing rate of approximately 40 rounds of ammunition per minute. The gun is trained and elevated (laid) by using separate power drives that are electrically controlled and hydraulically operated. Ammunition is served



3.123
Figure 5-35.—5"/54 Mount Mk 42, Exterior.

by an automatic, dual-hoist gun loading system that is hydraulically operated and electrically controlled.

The gun mount consists of the following main components:

1. Gun assembly
2. Slide assembly
3. Gun loading system
4. Gun laying system

The gun mount also contains the following auxiliary systems:

1. Sprinkling systems
2. Electrical systems
3. Heating, lighting, communication, and ventilation systems.

Basically, the gun and slide assemblies are standard, except that the breechblock and extractors are operated hydraulically. The 5"/54 gun is unique, in that it has roller bearings supporting the gun housing. The bearings prevent gun and mount lateral movement during recoil and counterrecoil.

Recoil and Counterrecoil

The gun recoil and counterrecoil systems are conventional, except that the location of the recoil pistons is changed, and the counterrecoil system differs in that two air chambers are used. The counterrecoil system is also arranged so that the differential and air chamber cylinders are mounted to the slide, and the piston rods bear against the after edge of the gun's main housing.

Gun Loading System

The gun loading system (fig. 5-36) extends from the ammunition handling room upward through the ship to the mount gun room. This loading system consists of a dual set of units which automatically serve rounds of semifixed ammunition to the gun from both sides of the slide.

Following is a brief description of ammunition movement from the handling room up through the loading system (fig. 5-36).

1. Rounds of semifixed ammunition are manually loaded onto the loaders (drums that automatically feed the lower hoist).

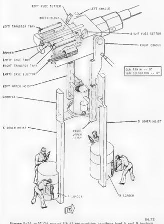


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Figure 5-36.—5"/54 mount Mk 42 ammunition handlers load A and B loaders.

2. The rounds of ammunition are fed from the loaders to the lower hoists, which raise each round to the carriers (on Mods 1 through 6) or to the transfer station (on Mods 7 and 8) which positions the round into the carrier.

3. The rounds are then transferred from the stationary lower hoists to the rotatable upper hoists (located on the structure of the gun mount) by the carriers.

4. The rounds are alternately raised from the carriers to the cradle by the upper hoists.

5. The rounds are transferred from the upper hoists to the transfer trays, located on each side of the slide, by the cradle which alternately swing upward.

6. The rounds are held in the transfer trays while the projectile fuzes are set (on mechanical time-fuzed projectiles only). The transfer trays then lower the rounds to the ramming position, in line with the gun chamber.

7. The rounds are rammed into the gun chamber by the rammers, which extend through the transfer trays.

After the gun fires and the breech is opened, the extractor catapults the empty powder case rearward into the empty case tray. This tray then lowers the expended case into the empty case ejector, which ejects the case from the mount.

Gun loading systems are divided into three groups as follows:

1. Lower gun loading system.
2. Upper gun loading system.
3. Intermediate section (ammunition carrier).

The lower gun loading system includes the loader drums and lower hoists (refer to figure 5-36), their hydraulic power units, and the control equipment necessary for their operation. This portion of the gun mount assembly is also referred to as the stationary, or nonrotating gun mount components (fig. 5-37).

The upper gun loading system consists of upper ammunition hoists, transfer trays, rammer, empty case tray, empty case ejector, and fuze setters (fig. 5-36). All upper gun loading system components are part of the rotating gun mount assembly and move with the mount when the gun trains (fig. 5-37).

The intermediate section (carrier) transfers rounds of ammunition from the fixed lower hoist to the rotatable upper hoist. In so doing, the carrier acts as an independent transferring mechanism between the stationary gun mount assemblies (lower gun loading system) and the rotatable gun mount assemblies (upper gun loading system). Physically the carrier is part of the carriage and receives its hydraulic power from the upper gun loading system supply.

Design Differences for Different Mods

All mods of the mount have the same basic design. The only major difference in the mount installations (except in the mod 9 and higher) is the design of the lower ammunition hoists and ammunition carrier. In the mods 1-6 mounts, the lower hoists and carrier are completely different from those installed in the Mods 7-8 mounts. The difference is clearly illustrated in figures 5-37 and 5-38.

LOWER HOISTS AND CARRIER.—In some mods (fig. 5-37), the lower hoists are straight and terminate directly under the tubes of the ammunition carrier. These hoists are cycled by control units that are operated by hydraulic pressure from an accumulator system. The hoist cycles are initiated by relay actuators in the control units.

In this hoist design, the rounds contained by the hoists move directly upward from the tops of the hoist tubes into the carrier tubes. When the carrier is loaded, it rotates to the upper hoists where the carrier ejectors transfer the rounds from the carrier tubes to the lower hoist tubes.

In other mods (fig. 5-38), some of the lower hoists are curved and some are straight, but each hoist has two ammunition handling tubes (one for hoisting, one for strikedown) and is operated by an electrically driven hydraulic power transmission which is stroked by a hydraulic servomechanism installed in a solenoid-operated control unit.

In this design, the hoist tubes are capped by transfer tubes located alongside the carrier tubes. The transfer tubes are units of the lower hoists and are operated by hydraulic pressure from an accumulator system.

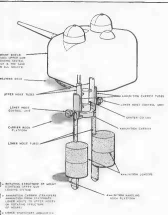

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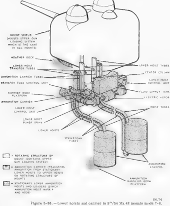
Figure 5-37.—Lower hoists and carrier in 5"/54 Mk 42 mounts mods 1-6.



84.74
Figure 5-38. — Lower hoists and carrier in 5"/54 Mk 42 mounts mods 7-8.

When the hoists are cycled, the rounds in the hoist tubes are elevated into the transfer tubes. From there they are ejected laterally into the opposite carrier tubes. The transfer tube ejectors then retract so that they will be in position to receive another pair of rounds from the lower hoists, and the carrier tube ejectors close over the rounds in the carrier tubes. The carrier then rotates to the upper hoists where the carrier ejectors transfer the rounds from the carrier tubes to the upper hoist tubes.

The strikedown tubes of the lower hoists are used for striking ammunition below to the handling room. When this is being done, the hoists are placed in local control so that they can be operated under power by means of hand-operated control cranks installed in the carrier room.

The cranks are arranged so that they can be used to stroke the hydraulic transmissions of their associated hoists. When either crank is turned, its hoist will cycle at a speed proportional to the rotational speed of the crank. When the crank is stopped, the hoist will stop.

The curved lower hoists are installed in mounts where the handling rooms are not located directly below the carrier rooms. This condition exists in all of the mounts in the CVA-class vessels and in the mounts in the DLG-class vessels.

The curve in the hoists of the forward DLG mount is very slight. In the CVA mounts, however, all of the hoists curve through two 90-degree angles and consist of vertical, curved, and horizontal tube sections.

MINOR DIFFERENCES IN MOUNT DESIGN.—Because of the variation in the vertical distance between the handling room and carrier room in different mount installations, the height of the lower hoists differs from mount to mount.

All mods of the mount have maximum gun elevation angles of 85 degrees and, with the exception of the CVA mounts, have 720 degrees of training freedom (360 degrees in either direction from the stowed position of the mount). Maximum angles of gun depression vary in different mounts from 7.5 degrees to 15 degrees, as determined by structural characteristics of the vessel.

Gun Laying System

The mount itself can be operated in either remote or local control. No provision is made for hand-powered operation. Handling drives are connected to the training and elevating gears, however, for stowing purposes and for use in connection with certain mount and gun alignment procedures involved in the installation of the train and elevation receiver-regulators.

The training and elevating gear assemblies are electrically controlled, hydraulically operated power drives that accurately position the mount and gun in response to electrical gun train and gun elevation orders. These orders can be applied to the train and elevation receiver-regulators from remote fire control or Gunar control stations (on certain mounts only), or from the one-man control units operated by the local control men in the mount.

The training gear assembly consists of a training gear, a power drive, and a receiver-regulator. The receiver-regulator converts the electrical gun train order signals into hydraulic control inputs to the power drive, which is an electrically driven, hydraulic power transmission. The output shaft of the power drive turns the training pinion, which drives the mount in train.

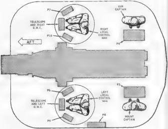
The elevating gear assembly consists of an elevating gear, a power drive, a receiver-regulator, and a firing cutout. The receiver-regulator converts the electrical gun elevation order signals into hydraulic control signals and applies them to the power drive, the drive turns the elevating pinion, and the pinion elevates or depresses the gun.

Both the training and the elevating gear assemblies are equipped with limit stop mechanisms. In the train receiver-regulator, the stop mechanism decelerates and stops the train drive as the mount approaches and reaches its limits of operation in either direction of train. The limit stop mechanism in the elevation receiver-regulator brakes the gun to a stop as it reaches its limits of travel in elevation or depression.

The firing cutout is connected by response gearing to the training and elevating pinion drive shafts, and operates switches in the firing circuit to prevent firing when the gun is pointed into danger sectors.

Personnel

The gun loading system and gun laying systems are separately controlled, and either system can



84.75
Figure 5-39.—5"/54 Mk 42 (mods 1-8) gun room stations and control panels.

be independently operated. Responsibility for control of the gun loading system is primarily delegated to the gun captain and the loader control man, whereas control of the gun laying system is the responsibility of the mount captain and the two local control men. Duties of the carrier control man are divided between the two systems. The duties of the gun crew (less ammunition handlers) for the 5"/54 are described below. Figure 5-39 illustrates the positions of the gun room crew and the control panels under their control.

MOUNT CAPTAIN.—The mount captain is in charge of the entire gun mount and receives all gun mount operation orders from weapons control via JP telephone circuits. He directs gun loading, gun firing and gun laying operations of the mount from the P-3 panel, using either telephone, lights, or a combination of these as a means of communication. The P-3 panel, located in the aft left-hand part of the gun room, is used primarily to select the station to control the gun train and elevation power drives.

GUN CAPTAIN.—The gun captain is in charge of gun loading equipment and gun loading crew and is directly responsible to the mount captain. He controls gun loading by means of switches on the P-4 panel. The P-4 panel is located in the after end of the gun mount, on the side of the gun opposite the P-3 panel. This panel contains switches and lights that enable the gun captain

to control and monitor gun loading systems operation.

LOCAL CONTROL MEN.—The two local control men (one on the left and the other on the right side of the mount) operate the mount in local by means of telescopes, one-man control units, and the P-6, P-7, P-9, and P-10 control panels in the local control stations. The P-6 and P-7 panels contain the knobs, dials, switches, and lights necessary for sight setting and local control operations.

An auxiliary local control panel is also located at each local control station—P-9 in the left station and P-10 in the right. These panels are used to control the telescope window wipers, telescope shutter heater, and windshield defroster system of each local control station.

A one-man control (OMC) unit is located in each local control station. Either OMC unit can provide the gun train and elevation orders necessary for local control operation. The left OMC has control only when it is relinquished by the right local control man or when the mount captain selects the left station by means of a switch on the P-3 panel.

CARRIER ROOM CONTROL MAN.—He controls the mount's electrical power supply system from the P-1 and P-2 panels located in the carrier control room. The P-1 panel contains the 440-volt electrical circuits that carry power to the various units of the entire gun mount system. Lights located on the face of this panel indicate when power is available to the system and when motors are running on the gun mount. The P-2 panel houses amplifiers for the fuze setters, parallax systems, and train and elevation power drives. On the face of this panel are switches and light arrangements that function as a means of communication between the gun captain and the carrier control man.

LOADER CONTROL MAN.—The loader control man is in charge of the handling room crew and ammunition handling equipment. He controls the loader drums by means of switches on the P-5 panel when the loaders are being operated in the manual power mode. The P-5 control panel, located between the A and B loader drums, enables the loader control man (with permission from the gun captain) to operate the loader drums in manual power operation. Normally, manual power operation is used during loading, unloading, exercising, or testing of the loader drums.

One Side Operation

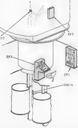
The gun captain can select one-side, automatic power operation of the loading system when a casualty occurs to some units of the loading system. The procedures necessary for one-side operation vary according to the unit of the loading system that is inoperative. Depending upon the nature of the casualty, the gun captain can deactivate one side of the gun loading system or instruct the carrier room control man to mechanically deactivate the malfunctioning unit. One-side operation (using one hoist) will reduce the gun rate of fire to about 20 rounds per minute.

One advantage of the gun loading system used with the 5"/54 gun mount is that once the drums are loaded the ammunition handling crew need not be on station for automatic gun firing operation. This enables a ship's weapon system to function during a condition of readiness with a minimum number of personnel. The ammunition handling crew, which consists of four powder men and four projectile men, can be utilized for other duties in the event of personnel casualties. The handling crew is needed only to replenish the 40 rounds of ammunition (in the loader drums) after a firing mission, or the men can be left at their station if more than 40 rounds are to be used.

5"/54 MK 42 MOD 9

The Mk 42 Mod 9 was designed for the main gun battery of DE 1053 class ships and is similar in many respects to the previous mods. However, three major differences exist between them. The big differences are in the train and elevation receiver-regulators, the fuze setters, and the electrical control system. These changes greatly reduced the weight of the mount. As an example, the weight of the fuze setter and its associated amplifiers alone was reduced from 432 pounds to 53 pounds (a reduction of 379 pounds).

The electrical control system was completely redesigned. The mount captain's P-3 panel and the gun captain's P-4 panel (part of earlier mods) have been eliminated. A new control panel (EP2), operated by the mount captain and located in the carrier room (fig. 5-40), now contain all controls previously embodied in the P-3 and P-4 panels. The local



84.76
Figure 5-40.—5"/54 Mk 42 gun mount control panels.

control station on the right side of the mount was eliminated. As a result, the number of on mount personnel was reduced from four to two (the gun captain and the OMC operator).

The design changes, in addition to weight reduction, greatly improved the reliability and maintainability of the receiver-regulators and increased the accuracy of the fuze setter.

5"/54 MK 45

5"/54 Mk 45 light weight gun mount (fig. 5-41) offers outstanding reliability and maintainability and is served by a minimum complement of personnel. The mount is operated, monitored, and exercised remotely; personnel do not enter the gun house except for maintenance. A safety key located on the EP2 panel disables all circuits before the crew enters the gun house. One mount operator performs most switching functions (as directed) for complete gun mount operation. The ammunition handlers load projectiles and powder cases into the automatic loading station. The mount loader drum holds 20 rounds in ready service. The loading station permits replenishing the loader drum during sustained firing without interrupting the fire mission. The load and fire cycle can be interrupted if a special-purpose type of ammunition, such as star shell, is to be used, or if a misfire-clearing charge is needed.

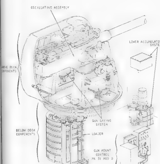
The mount design emphasizes safety. The crew needs not enter the gunhouse to extract misfires. Misfires can be extracted automatically and rapidly. By loading a clearing charge, the gun can be cleared and returned to service without personnel entering the gunhouse. Unloading is also accomplished automatically. The rounds not fired are returned to the hoist unload doors in the loader drum.

Gun Mount Components

The mount has two physical component groups: the lower structure (below deck) and the upper structure (above deck). The lower structure delivers an uninterrupted flow of ammunition to the upper structure. It includes the mount control system, loader drum, fuze setter, hoist, and lower accumulator system. The upper structure includes the stand, carriage, cradle, slide, gun barrel, upper accumulator system, gun laying system, and shield.

CONTROL SYSTEM

The mount control system consists of two control panels—the EP1 power panel and the EP2 control panel. The power panel (EP1) receives power from the ship's supply and distributes it within the mount and other panels. The control panel (EP2) permits selecting the



84.83
Figure 5-41.—5"/54 Mk 45 gun mount (general arrangement).

various modes of mount operation and serves as the test board and local control for the gun laying system and the fuze setter.

The gun laying system has separate train and elevation power drive assemblies, which position the gun in train and elevation respectively. These assemblies are controlled electrically and operated hydraulically in response to orders from either a remote fire control system or the on-mount local control system. A firing cutout system opens the firing circuit whenever the gun is positioned to a nonfiring zone.

The mount local control system permits total system exercise and test. One man can activate and exercise the mount and verify mount operation ability in less than 5 minutes. A troubleshooting status board located within the EP2 panel is used in conjunction with indicating lights and dials to pinpoint the cause of mount stoppage. Standardized parts are used widely, and many of the amplifiers and logic printed circuit cards are physically and functionally interchangeable.

TURRETS

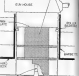
Turrets are heavy armored gun structures of at least 6-inch caliber and usually equipped with 3 guns. They are the primary offensive armament of conventional cruisers and battleships (most of which are in the reserve fleet). They are located on the centerline so that they can fire to either beam. Each gun of a multiple gun turret has a separate slide mounted in trunnion bearings and is arranged for either independent or joint elevation movement.

Some similarities exist between gun mounts and turrets. The major difference between them is that the turret's structure is protected by armor plate.

The gunhouse, or turret proper (part that shows above deck), is mounted on roller bearings within the armored structure (barbette); it is rotated by an electric-hydraulic power drive that can be controlled automatically or manually. The barbette surrounds the turret's rotating structure below the gunhouse and extends to the ship's armored decks.

TURRET STRUCTURAL ARRANGEMENT

The major parts of a typical turret are illustrated in figure 5-42. Each part is made up of separate levels that contain the major assemblies and subassemblies of a turret. Although a turret's construction will vary according to its function and differ in many mechanical details, generally its installations will contain all or some of the levels shown in the preceding figure and discussed below.



84.141
Figure 5-42.—Turret structure fixed and rotating elements.

The first level (gunhouse) contains the turret's fire control and communication equipment necessary for turret control. Each gun compartment, or gun room, contains the power equipment necessary to operate and service each gun.

The second level, called the pan floor of pan plate, contains the pockets (gun pits) into which the breech end of the guns are depressed as the gun elevates. It also contains some of the machinery for the train and elevation systems.

The third level is the machinery floor where most of the power equipment for turret operation is located. In some turret systems the stations for gun laying, both in train and elevation, are also located on this level. In most

turrets, however, these stations are located within the gunhouse.

The next three levels are the upper and lower projectile flats, and the powder handling platform. The projectiles stowed on the projectile flats are loaded into hoists and lifted up into the gunhouse. The powder handling platform is surrounded by powder magazines which stow either bag or case type propelling charges. These charges are passed from the magazines, through flameproof openings called powder scuttles into the handling platform (room). The charges are loaded into elevator type hoists which deliver them to the gunroom.

The center column (fig. 5-42) and the bulkhead which surrounds it are fastened to the pan floor (plate). They extend through, and support the three levels of the suspended structure. The suspended structure contains the last three levels mentioned above and is part of the rotating structure of the turret. The combined weight of the rotating structure is supported by the roller bearings located on the pan plate.

The general principles of a gun mount's major components discussed early in this chapter, also apply to the turret's components with one major difference. In a turret, the slide, housing, and gun barrel are supported by girders (fig. 5-43). They serve the same purpose as a gun mount's carriage checks shown in figure 5-3.

CLASSIFICATION AND TYPES OF TURRETS

Turrets can be classified by the type of guns they employ, either case or bag type guns. Case guns are those in which the propelling charge is encased within a metal cartridge case; a bag gun is one in which the propelling charge is encased within a fabric container called a powder bag.

Four different types of turret installations are on present Navy ships, active and reserve fleet. Two of these turrets (6''/47 and 8''/55 rapid fire) are equipped with case guns and two (8''/55 bag gun and 16''/50 bag gun) are equipped with bag guns.

REPRESENTATIVE TURRETS

Most ships having turrets are in the reserve fleet. Therefore, turrets will be discussed only briefly.

Case-Gun Turret

A 6-inch caliber three-gun turret is divided into four manned spaces and requires forty men to man the various battle stations for normal turret operation. Twenty-two crew members are stationed within the gunhouse (fig. 5-44)—sixteen in the turret's gun compartment and six in the turret officer's booth. The men stationed in the gun compartment are: (1) two gun-laying operators, (2) a sightsetter, (3) three gun operators (gun captains), (4) three powder hoist men, (5) three powdermen, (6) three shellmen, and (7) a gunner's mate repairman. Stationed in the turret officer's booth are four turret controlmen—the turret officer, turret captain, computer operator and ammunition supply talker—and two rangefinder operators. (Rangefinder operators are not required for turrets without rangefinders.)

The duties of the turret's crew (except for the computer operator, ammunition supply talker, and rangefinder operators) are very similar to

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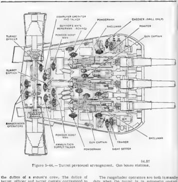
Figure 5-43.—Gun girders.



54.87
Figure 5-44.—Turret personnel arrangement. Gun house stations.

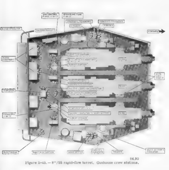
the duties of a mount's crew. The duties of turret officer and turret captain correspond to those of the mount captain and his assistant. Other stations compare accordingly. The turret's ammunition supply talker transmits orders from the turret officer or turret captain to ammunition handlers and loaders.

The computer operator is responsible for the computation of the fire control problem when the turret is in local or hand control. He introduces certain inputs into the auxiliary computer to produce sight angle and sight deflection, which are transmitted to the sightsetter by phone.

The rangefinder operators are both in standby duty when the turret is in automatic control. In local or hand control, they provide ranges to designated targets. They are also called on to spot in range and make initial target angle and speed estimates.

Seven men are stationed on the projectile handling level and ten are in the powder handling room.

The 8" caliber three-gun turret is installed in Salem class heavy cruisers. Although the



84.90
Figure 5-45.—8"/55 rapid-fire turret. Gunhouse crew stations.

foundation structure, barbette, and magazine are of a standard turret design, the ammunition loading system is an entirely new design. The guns operate automatically and require no shellmen or powdermen within the gun compartment. The turret has automatic fuze setting and radar equipment instead of optical rangefinders.

Forty-four men are required to man the battle stations of this turret installation, seventeen in the gunhouse and twenty seven in the levels below the gunhouse. The gunhouse crew members are shown in figure 5-45. (The checker is a member of the crew in training operations only; his station is not manned in battle action.)

Bag-Gun Turret

Bag-guns differ from case-guns in their methods of handling, transferring, and loading ammunition. Since bag type ammunition needs greater safety in handling, each gun within the gunhouse and the powder hoist which services each gun are arranged in separate flameproof

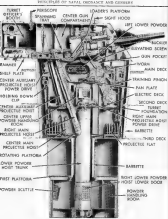
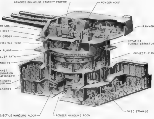


Figure 5-46.—8"/55 bag-gun turret.



110.53.2
Figure 5-47.—Cutaway view of 16-inch turret.

compartments and structures. A flame seal located at the upper end of each powder hoist isolates the lower powder handling rooms from each gun compartment.

Turrets equipped with bag guns are essentially similar. The 8-inch and 16-inch turrets differ in many mechanical details, but in general their installations and equipment perform the same basic function.

Cutaway views of the 8-inch and the 16-inch turrets are shown in figures 5-46 and 5-47 respectively.

CHAPTER 6

GUN WEAPON SYSTEMS

You already know, from reading earlier chapters in this text, that guns were in use hundreds of years before the weapon system concept was dreamed of. Guns were, with only minor exceptions, THE weapons (in various shapes and sizes) for all naval warfare until almost the beginning of the 20th century. As guns improved in accuracy, rate of fire, and range, the rough-and-ready methods that had hitherto sufficed for placing gun projectiles with maximum effect were refined until modern techniques and equipment for fire control were developed. As submarines and aircraft added more weapons to the naval arsenal, as well as new varieties of targets for the weapons to engage, the gun lost its primacy as the principal naval weapon and became what it is today—one of the several major classes of weapons, each with its characteristic range of applications and types.

The weapon system concept as applied to guns and their associated equipment differs somewhat from its application to such newer weapon systems as guided missiles and their associated equipment. Missile systems are characteristically integrated—they are conceived, engineered, and designed as systems. Although gun weapon systems function effectively as systems, they are more flexible and less integrated. Thus, a given fire control system may function equally well with any of several types of gun mount, or a gun mount may continue to function with an alternate fire control system or even with only the sights in the gun mount if its primary fire control system is knocked out.

ELEMENTS OF A GUN WEAPON SYSTEM

Functionally a gun weapon system includes the following elements:

1. A fire control system.
2. One or more gun mounts organized as a BATTERY.
3. Ammunition supply arrangements.

Since it is inherently flexible both in function and in the equipment that goes to make it up, a gun weapon system is not invariably composed of the same elements—in fact, the combination of the elements that make up a system may vary during a single exercise or battle action. However, a given combination is generally recognized as best—that is the PRIMARY arrangement—and others (SECONDARY arrangements) may be substituted if required by battle casualties or for training purposes. This chapter will concentrate on the preferred combinations that make up the primary systems.

Today all but a few gun weapon systems are either primarily designed for action against air targets (these are antiaircraft or AA systems), or are equally well adapted for engaging air or surface targets (these are dual purpose or DP systems). A few systems designed primarily to engage surface targets can be adapted for certain antiaircraft applications, but these will not be the focus of attention in this text. This chapter is mainly concerned with a typical dual-purpose and a typical antiaircraft gun weapon system.

GUN BATTERIES

The guns on any naval vessel are organized into groups or batteries, each consisting of several gun mounts of similar size and ballistic characteristics. This simplifies the control of gunfire, the supply of ammunition, and maintenance. The size and number of guns in a battery depends on the type of ship.

There are several ways to classify gun batteries aboard ship. The simplest is to use the bore diameter (caliber) and the number of calibers as we have done in chapter 5. It

practice, the number of calibers is very often omitted in the ship's battery designations, at least when referred to by members of the crew. Thus, a battery of 6"/47 caliber turrets is a 6" battery, and so on. The length of bore in a 5" battery is also dropped from the designation because a ship will have either a 5"/38 or a 5"/54 battery, but not both. Keep in mind that these shortened terms are valid only within your ship or for ships with the same armament. The batteries must be accurately identified in other circumstances. The 5"/54 Mk 42 and the 3"/50 rapid fire, described in chapter 5, must be further identified within their caliber because of the operating differences between these mounts and the older 5"/54 and 3"/50 mounts. A few cruisers (most, if not all, of which are in the reserve fleet) have rapid fire 6-inch or 8-inch turrets that require more identification since they differ from their slow-fire prototypes. The 40-mm and 20-mm guns are not described in terms of their number of calibers; they are designated by bore diameter only, as are other guns smaller than 3-inch.

Batteries also are classified as main, secondary, and machinegun batteries, depending on the type of ship in which they are mounted. Traditionally, the largest caliber of guns on board is the main battery; the next largest, the secondary battery; and the remaining installed guns are either heavy or light machinegun batteries. Thus, a 5" battery is the main battery of a destroyer, but only the secondary battery of a cruiser. This method of classifying becomes further complicated when ships sometimes extend the term "main battery" to mean the weapon of greatest potential effect; for example, the planes of an aircraft carrier, or the torpedoes of a submarine. The terms "main armament" and "secondary armament" are used extensively in call-for-fire gunfire support missions.

The last (and probably the best) method classifies batteries according to their service application as follows:

1. SURFACE BATTERY—a battery that is designed primarily to combat surface targets (including shore-bombardment or gunfire support). This battery, sometimes called single purpose, is comprised of 6" or 8" turrets mounted on cruisers. (Turrets can be used against air targets, but this is not their primary application.)

2. DUAL PURPOSE BATTERY—a battery that is designed to combat both air and surface targets (including gunfire support). Dual purpose batteries are 5" guns only. Dual purpose relates not so much to the 5" gun's versatility, as it does to the dual-computing devices and methods in the fire control system.

3. AA BATTERY—a battery that is designed primarily to combat air targets. This battery normally has 3" guns. The 3" gun can also be used against surface targets, and for "direct fire" missions in gunfire support.

FIRE CONTROL IN GUN WEAPON SYSTEMS

In any weapon system the fire control problem is essentially that of getting the weapon or projectile to hit the target and explode, or at least to explode when the target and weapon or projectile approach close enough for maximum damaging effect. In gun weapon systems the problem is to lay (aim) the gun in such a way that the projectile will hit or approach close to the target. In some other types of weapon systems the weapon is self-propelled and contains guidance equipment so that it is capable of homing on the target (i.e., it can detect the target and follow it, ultimately catching up with it), or other guidance methods may be available. This is not true of gun weapon systems. Once the projectile has left the gun muzzle, nothing further can be done to affect its course. The gun's fire control problem must be solved before the gun fires.

In this section we shall discuss basic interior ballistics, variables in the fire control problem, the elements of fire control systems, and finally the process by which these elements are used in solving the fire control problem.

BASIC INTERIOR BALLISTICS

First of all, what is ballistics? Ballistics is the science of the motion of projectiles. It is divided into two branches, interior and exterior ballistics. Interior ballistics is that branch of the science which deals with the motion of the projectile while it is in the gun. The initial velocity (I.V.) of the projectile is a result of the forces involved in the general term, interior ballistics. Exterior ballistics pertains to the projectile after it leaves the gun. Obviously I.V. is the one value common to both interior and exterior ballistics.

Gun design is essentially a compromise. The gunner wants maximum I.V. for great range and flat trajectory; the designer must consider

the strength of his gun and desires minimum wear and erosion. Interior ballistics includes the study of (1) the combustion of the powder, (2) the pressure developed within the gun, (3) the variations in pressures and velocities with changes in any of the "conditions of loading," and (4) erosion of the bore.

Propellants and Burning Rate

Propelling charges are designed to burn in the chamber of the gun in such a way that they will develop maximum projectile velocity without excessive heat, pressure, or erosion. Ideally, the most efficient propellant for a gun would be so balanced that the charge is entirely consumed immediately before the projectile leaves the muzzle.

To approach this ideal, propellant burning rate must be controlled, so that the propellant will be suited to the specific gun in which it is to be used. The dominant factor in determining burning rate of a given propellant composition is the surface area per unit weight of propellant. The greater the area per unit weight, the faster the burning rate. (Other but less significant factors include the percentage of nitration, moisture content, content of volatiles, and the stabilizer used.)

As you know, gun propellent compositions are manufactured as homogeneous cylindrical grains of uniform diameter, length, and number of perforations (fig. 6-1), with larger grains for larger caliber guns. For a given muzzle velocity, larger caliber guns require a slower burning propellant than smaller caliber guns, since the distance the projectile must travel to the muzzle is proportionately longer and the powder must burn for a longer time. Other things being equal, larger grains have smaller area per unit weight, hence slower burning rate.

Propellent powder grains for guns 40-mm and larger have 7 perforations. Since burning rate climbs rapidly in smaller size powder grains, there is only one perforation, or none at all, in grains for calibers smaller than 40-mm.

A propellant's potential is the total work that the gases of combustion could perform while expanding from the solid state to the space they would occupy when fully expanded to atmospheric pressure and when cooled to a specified temperature.

In the average conventional gun, some 60 percent of the potential disappears in muzzle

53,144

Figure 6-1.—Perforated propellant powder grains.

loss; 30 percent is transmitted to the projectile, and all other losses—such as heating the projectile and gun, causing the gun to recoil, and so forth—amount to about 10 percent.

Gun Strength Vs. Propellant Pressure Relationships

Figure 6-2 illustrates a basic principle of gun design. The figure may be taken as typical of the strength-pressure relationship in modern guns. Note that the high breech strength is carried well forward of the point of maximum pressure. The gun strength at every point must exceed the powder pressure at that point by an amount that will provide a suitable margin of safety.

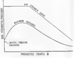


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Figure 6-2.—Typical gun strength and pressure curves.

The curve as it appears in figure 6-2 shows pressure beginning at a value well above zero. This indicates the pressure build-up that occurs after the propelling charge begins to burn but before the projectile begins to move. (The x-axis in the figure represents projectile movement in the bore, not time or bore length.) The projectile begins to move only after the propellant gas reaches the initial forcing pressure required to initiate movement of the projectile in spite of projectile inertia and the engagement of the rotating band in the rifling.

Note that the gun strength curve is represented as a straight horizontal line above the area between the point of initial forcing pressure and the point of maximum pressure. It does not vary in parallel with pressure curve. The reason is that the same pressure that the expanding gases exert against the base of the projectile is exerted equally against all interior surfaces of the gun behind the projectile. Hence the breech part of the barrel must be designed for the maximum stress to be imposed.

After the projectile passes the point of maximum pressure, it continues to be accelerated by gas pressure until it leaves the muzzle. The total area under the curve, up to the point where the projectile leaves the gun, is a rough measure of initial velocity, and the pressure remaining at the muzzle is an indication of the muzzle loss. A high muzzle pressure increases muzzle flash.

Changes in "Conditions of Loading"

By "conditions of loading" are meant the powder used, the weight of charge, the density of loading, the volume and form of the powder chamber, and the weight of the projectile.

POWDER USED AND WEIGHT OF CHARGE.—Powders are termed quick and slow in reference to their rate of combustion in a particular gun. For instance, a small-grain powder is quicker than a larger grain of the same shape, since all the grains would be consumed in a shorter time. Not only will the larger grain increase the time required for burning the charge, but it will also cause maximum pressure to be lower and to be reached later in the travel of the projectile. The gun pressure curves shown in figure 6-3 compare slow powders and quick powders where the same weight of charge was used.

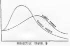

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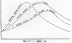
Figure 6-3.—Typical gun pressure curves showing variations due to quickness of powder, same weight of charge.

Within limits, the muzzle velocity for a particular gun may be increased without causing excessive pressure by increasing the size of the charge and at the same time using a powder that burns more slowly. See figure 6-4.

DENSITY OF LOADING.—Density of loading is the ratio of the weight of the charge of powder to that of the volume of water which, at standard temperature, would fill the powder chamber. It is a measure of the amount of space in which the gases of combustion may expand before the projectile begins to move.



110.59
Figure 6-4.—Typical gun pressure curves showing methods of obtaining increased muzzle velocity in a gun without increasing maximum pressure.

A high density of loading leaves but little space for initial expansion; consequently pressure builds up rapidly. The maximum pressure behind the projectile is reached early in the projectile's movement through the bore. With lower density of loading, more expansion of the gases may take place before the projectile starts to move. The maximum pressure is achieved later, and this maximum is lower than that with high density of loading. (Compare the curves in figure 6-5.) Other factors remaining equal, increased density of loading increases maximum pressure, muzzle velocity, and muzzle loss.

The densities of loading at present vary between 0.4 and 0.7, depending on the caliber of the gun and on whether the charge is case, stacked bag, or unstacked bag. Since the specific gravity of smokeless powder is about 1.6, the following relationship holds:

$$\text{Density of loading} = 1.6\,v,$$

where

v = the proportion of the total chamber volume which is filled by the charge.

Hence it is apparent that a loading density of 0.4 would require a charge filling 25 percent of the chamber volume, and a loading density of 0.7 would require a charge filling 45 percent of the chamber volume.

When the density of loading drops markedly below the above figures, irregularities of muzzle velocity may be expected. The pressure

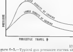


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Figure 6-5.—Typical gun pressure curves showing variations due to density of loading.

builds up irregularly instead of smoothly, and the high point may be reached at the wrong time.

A practical example of the importance of loading density would be a projectile lodged part-way down the bore of a gun, greatly increasing the effective chamber volume. Besides greatly lowering density, and causing pressure waves which may build up beyond a safe limit, it extends the area of maximum pressure beyond the area of maximum barrel thickness. A normal powder charge used to dislodge a projectile so positioned might cause the gun to burst, or at least bulge, immediately behind the projectile.

Very high density of loading, on the other hand, may cause detonation of the propelling charge, again resulting in a burst gun.

VOLUME AND FORM OF POWDER CHAMBER.—The designers of the gun, having established first the desired muzzle velocity, then the limiting maximum pressure allowable in the gun (determined from study of gun construction), can proceed to determine the volume and form of the powder chamber and the weight of the charge. In a particular gun, the volume and form of the powder chamber change only because of erosion at the origin of rifling and improper seating of the projectile, causing irregular muzzle velocity.

Projectiles differing in weight—for example, high-capacity and armor-piercing types—can be fired from a given gun. High-capacity projectiles, being lighter, will have a slightly higher muzzle velocity.

Summary of Interior Ballistics

There is much more to interior ballistics than has been taken up in this section, but you have read enough here to grasp the general nature of this branch of gunnery. Here are repeated the main points of the discussion, by way of summary:

1. Using the same weight of charge, a slow powder produces a smaller maximum pressure than a fast powder, and attains this maximum pressure later in the travel of the projectile.

2. Increasing the weight of a charge of powder of a given grain size increases the maximum pressure attained and causes this maximum to occur earlier in the travel of the projectile.

3. Because of muzzle loss and irregularity of muzzle velocity, slow powders are less efficient than fast powders.

4. The muzzle velocity of a given gun may be increased within limits by using larger charges of slower propellants.

VARIABLES IN THE GUN FIRE CONTROL PROBLEM

To solve the fire control problem, it is necessary to consider three main types of variables—

1. Exterior ballistics.
2. Target position and relative motion of the target and own ship.
3. Inherent corrections necessitated by the physical characteristics of the weapon system.

Each of these is discussed separately below.

Exterior Ballistics

From the instant it leaves the gun muzzle until it ends its flight by impact or explosion, the gun projectile's path or trajectory is affected by the following factors:

1. MOMENTUM. As you remember from Newton's laws of motion, any material object has inertia, and, if moving, tends to continue its motion at constant velocity (i.e., at constant speed in a straight line). The important values in determining the momentum of a projectile are its I.V. (initial velocity) and its mass. I.V. is measured in feet per second (usually abbreviated fs) as the projectile leaves the gun muzzle. Mass is conventionally measured in pounds (a convenient measure, if not strictly correct scientifically). If no other factors affected its motion, any gun projectile would have a straight-line trajectory. Note also that all naval guns (except a few special purpose devices) are designed to make the projectile spin at high speed on its long axis. This makes the long axis of the projectile tend to maintain a fixed attitude in space while in flight.

2. GRAVITY. On the earth's surface all material objects are subject to the earth's gravitational attraction, which pulls them toward the earth's center. Any unsupported object therefore tends to fall at a constant acceleration of about 32 feet per second per second. Gun projectiles are unsupported once they leave the muzzle; unlike aircraft, they are not airborne, and unlike rockets, they are not supported by propellant thrust. They therefore fall with the same acceleration as if they had been dropped, not fired. The idea may be novel to the student, but the fact is that a projectile fired from a horizontally aimed gun will strike the surface of the sea at the same instant as a similar projectile that has merely been dropped from the same height above the water. It is, of course, true that the fired projectile will hit the water some distance away (fig. 6-6A).

Under the influence of momentum and gravity (but of no other factors) the trajectory of a projectile will be one of a family of symmetrical curves called parabolas. For a given I.V. and projectile mass, the projectile will then travel farthest from the gun if the gun barrel is elevated to make a 45° angle with the horizontal (fig. 6-6B).

3. AIR RESISTANCE. A projectile traveling at a speed of up to 3,000 feet per second creates a considerable disturbance in the air. At such speeds, air at sea-level density is far from insubstantial, and its resistance significantly slows the projectile throughout its flight. Air resistance affects the trajectories of all projectiles, but its effects, which depend on air density, are much greater on less massive ones.

The trajectory as affected by momentum, gravity, and air resistance is still more or less parabolic, but is not symmetrical; the projectile is traveling slower as it approaches the end of the trajectory, and (fig. 6-7) it falls at a larger angle with the horizontal (tending toward 90°).

4. WIND. Wind is air movement. Movement of the air with respect to the earth is called true wind. Air movement caused by the motion of a ship is called relative wind for that ship. Apparent wind is the vectorial sum of these two winds, and it is the quantity read from the ship's anemometer. Wind speed is measured in knots, and wind direction in degrees from the reference (true north, or ship's bow) clockwise to the direction FROM which the wind is blowing. By vectorial analysis, apparent wind can be resolved into relative wind and true wind. True wind is the wind input to fire control computers. True north is the reference for true wind, thus true wind is independent of ship's movement; however, both relative wind and apparent wind depend on own ship's course and speed.

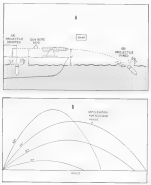

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Figure 6-6.—Projectile trajectory as affected by gravity. A. Projectile (B) fired from horizontally aimed gun strikes water surface at same instant as projectile (A) dropped from same height. (Height H = height H'.) B. Theoretical parabolic trajectories in vacuum at various gun elevations.

12.4
Figure 6-7.—Comparison of vacuum and air trajectories.

In fire control computers, true wind is resolved into two components with respect to the line of fire. One, called range wind, lies in the line of fire and may either accelerate or decelerate a projectile. Cross wind is the other component; it blows at right angles to the line of fire moving the projectile to the left or right of its planned trajectory. These components and their effects are automatically computed, and automatic corrections are made to the gun's position in train and elevation.

A ship's anemometer measures surface wind, but a projectile's trajectory passes through various altitudes. These altitudes, primarily because of air density and temperature, have different wind velocities than those on the earth's surface. A ship's meteorologist can track the flight of a balloon and measure the velocities and directions of tropospheric winds. Or, periodic wind reports are often received by radio from a shore station which has better wind measuring facilities. Most ships do not have a meteorologist on board; they depend on reports from other ships or stations. Ballistic wind, which is determined by aerological observations, is the resultant wind vector from zero altitude to about 20,000 feet. But if the projectile's maximum ordinate is less than 20,000 feet, only the wind affecting the projectile is considered in the ballistic wind computation. Wind velocities and directions are measured in 2500-foot increments (layers) from the surface horizontal to 20,000 feet. Weighted factors are provided in the manual so that any number of increments can be used easily and quickly. The number, of course, depends on the projectile's maximum ordinate. All necessary data for air and surface targets, including various altitudes and ranges, and various guns used, are provided in the manual. The final ballistic wind calculation for a particular type of engagement, at a specified altitude and range, is substituted for true surface wind in the fire control computer. In the absence of ballistic wind data, true wind (surface) is the computer input.

5. DRIFT. Drift (fig. 6-8) is a deflection of the trajectory to the right, and is caused by the interaction of gravity, air resistance, and the projectile's clockwise spin. (Counterclockwise spin would deflect the trajectory to the left, but all naval guns except the .45 caliber have clockwise rifling.) Drift is directly proportional to range. It is independent of wind.

6. EARTH'S ROTATION AND CURVATURE. The discussion so far has implicitly assumed that the earth is flat and does not rotate. For ranges up to 20,000 yards or so, such an assumption does not cause any serious errors in fire control. At extreme gun ranges (30,000 yards and more) these two factors become important enough to be taken into account, particularly in firing at surface targets. Since such ranges are characteristic of the surface batteries of heavy cruisers (of which there are only a few in the active fleet) and those of battleships (none of which are in the active fleet), we can neglect these effects in this text.

Target Position and Relative Motion of Target and Own Ship

In the fire control problem, target position at any instant is measured in terms of target bearing (a horizontal angle measured from a vertical reference plane), target elevation (a

84.200
Figure 6-8.—Clockwise projectile spin causes drift to the right.

vertical angle measured from a horizontal reference plane), and range (a linear distance measured along the line of sight (LOS) to the target (fig. 6-9)).

As you noted at several points in connection with the discussion of exterior ballistics, the effect of the factors listed in the preceding article depends on, among other things, range. Another way of putting it is to say that they depend on time of flight—i.e., the time lapse between the projectile's departure from the gun muzzle and its impact or explosion. During this time the factors that determine the projectile's trajectory have their effect; obviously, the longer the time of flight, the greater their effect. Since, other things being equal, at any specified I.V. time of flight is proportional to range. This is one reason that it is important to know the range to target (generally measured in yards) as accurately as possible. Range to an air target, as measured along the LOS, is called slant range to distinguish it from range measured on the surface.

There are two kinds of target bearing. Relative target bearing is the angle, measured clockwise in degrees and minutes, between a vertical plane through the centerline of own-ship and the line of sight (LOS) to target. (This is illustrated in figure 6-9.) True target bearing is measured similarly, but from a vertical plane containing a line to true north. Figure 6-10 shows the distinction and relationship between true and relative bearing, and demonstrates that true

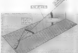

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Figure 6-9.—Relative target bearing, slant range, and target elevation.

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Figure 6-10.—Relationship between true bearing, relative bearing, and own ship course.

bearing is the algebraic sum of own ship course and relative bearing.

For the location of an air target with respect to own ship, one more value is needed—target elevation (generally measured in minutes of arc from the surface horizontal plane.)

If now we were to assume that the target and own ship were stationary with respect to each other, it would be necessary to correct only for exterior ballistic factors and the gun would be laid for a hit on the target. However, such a situation is rare. Target movement with respect to own ship is a part of every practical fire control problem, and it becomes increasingly important as ranges decrease and target velocities increase. (You can expect some air targets to be moving at over 600 knots.) In fact, at very close ranges (in the neighborhood of 2,000 yards or less) the ballistic factors are completely overshadowed in importance by corrections for target velocity, and many of the ballistic factors are not even considered in fire control systems designed for close-range work. This is true because at short ranges

(a) time of flight is short

(b) angular velocities (i.e., changes in target bearing and target elevation) increase as target range decreases, even when target speed as measured in knots remain the same.

(c) time available for arriving at solutions to the fire control problem is so short that there is time only for essential steps in solution.

Inherent Corrections to the Fire Control Problem

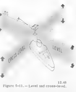
The miscellaneous factors that we lump under the label INHERENT CORRECTIONS include corrections for:

1. Motion of the gun platform (i.e., the ship's rolling and pitching motions as it floats on the water).
2. Parallax — i.e., distance between fire control system elements located at different points aboard ship.
3. Divergence of gun mount roller paths from the deck reference plane.

These factors are called "inherent" because they are unavoidable. All ships afloat have some rolling and pitching motion; parallax exist between the different elements of a gun fire control system aboard ship; and the roller paths of gun mounts cannot be machined perfectly parallel to the deck of the ship.

CORRECTIONS FOR GUN PLATFORM MOTION. — As you remember, the essence of fire control is to position the gun barrel so that the projectile's trajectory will culminate in its collision with the target. We may (as we did earlier in this chapter) assume for purposes of analysis that the deck on which the gun mount stands is stable, but in practice it is not generally possible to make this assumption. Nor is it practicable to stabilize the deck itself. Instead, either of two alternative correction methods is used. One requires that the gun be continuously repositioned by its power drive so that it maintains the desired attitude regardless of the ship's roll and pitch. The other (less frequently used) is to control the firing circuit so that as the ship rolls and pitches the firing circuit is energized only during those instants when the gun happens to be in the position required for hitting the target.

Corrections are required for the effects of ship's roll and pitch. They are level and cross-level (fig. 6-11) and trunnion tilt. Level is the angle that the deck plane, which rolls and pitches with the ship, makes with the horizontal, as measured in a vertical plane containing the line of sight (LOS). Crosslevel is measured at right angles to level.



12.48
Figure 6-11. — Level and cross-level.

Inclination of the deck across the line of sight causes trunnion tilt. As the gun mount tilts with ship's motion, the gun no longer elevates in a plane perpendicular to the horizontal. This introduces errors, both because the gun does not elevate to the proper angle and because elevation in a plane not perpendicular the horizontal causes the gun to shift in train. Thus at a chosen instant, if the right trunnion is lower than the left, elevating the gun by X number of minutes with respect to the horizontal will require more than X minutes of elevation in the tilted plane. Additionally, the barrel, after elevation, will be displaced to the right of the plane it was in before elevation. Figure 6-12 shows the corrections required to compensate for trunnion tilt.

PARALLAX CORRECTIONS. — In general, parallax is the apparent displacement of an object (for example, a target) as seen from two different locations. The phenomenon occurs in several different contexts in fire control. We are now concerned with the effect diagrammed in figure 6-13. Relative target bearing is different at each gun mount and at the director. The parallax correction compensates for these differences.

CORRECTION FOR ROLLER PATH TILT. — Ideally, the roller path of each gun mount should

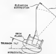


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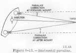
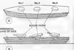
Figure 6-12. — Corrections for trunnion tilt.



12.46
Figure 6-13. — Horizontal parallax.

be parallel to that of the reference unit (director in most cases). Although the tilt of a gun mount with respect to the reference is, in modern naval construction, always small (rarely over a degree, and usually much less), it must be corrected. Some tilt is unavoidable because a ship's hull is supported much differently in the shipyard than it is when afloat. Individual corrections are required for each gun mount. The correction is made in elevation, but its magnitude depends on the angle to which the mount is trained. Figure 6-14 shows the effect of roller path tilt in exaggerated form.

Roller path tilt correction is performed mechanically by a device built into each gun mount. The computer in the fire control system has nothing to do with this correction, which is different for each mount. Chapter 8 illustrates one



12.47
Figure 6-14. — Effect of roller path inclination (much exaggerated).

type of roller path tilt corrector, and briefly describes how it is used.

ELEMENTS OF GUN FIRE CONTROL SYSTEMS

As you noted earlier, the complexity of the fire control problem, and hence of the fire control system necessary for its successful solution, increases with the maximum range of the guns associated with the system, since ballistic factors are relatively more important when the time of flight is longer. At the same time, at shorter ranges the position and motion of the target with respect to own ship become relatively more important than the ballistic factors. Moreover, at shorter ranges the time available for solution of the problem is much more limited than at longer ranges. Consequently, instead of a single "universal" fire control system or type of system used in all applications, you find that there are two main types, each best adapted to a particular kind of application. One of these is the relative-rate type, which efficiently deals with fast targets at short ranges. The other is the linear-rate type, which is particularly well adapted to deal with the more complex ballistic computations required for distant targets.

Examples of both types will be described in more detail later in this chapter, but so that you may understand better the description that follows of how the fire control system solves the fire control problem, consider briefly the elements of each type.

Linear-Rate Systems

Linear-rate systems are used for both surface and air targets at much longer ranges than those for which relative-rate systems are generally used. The system consists of (fig. 6-15) a director located high in the ship's structure, a computer and stable element closely linked to each other and located in a plotting room in the hull, a radar console located either in the plotting room or the director, and gun mounts (commonly the 5-inch battery, though the system can be connected to control other mounts also). All these elements are interconnected by electrical data transmission circuits, except that the stable element may be mechanically or electrically connected to the computer.

The director is equipped with telescopes, an optical rangefinder, radar equipment (in some installations), data transmitters and receivers, and power drives, so that it can:

a. Determine target bearing, elevation, and range either optically or by radar.

b. Be power driven by computer-generated signals enabling the director crew to verify that the computer is developing the proper fire control solution.

c. "Lock on" the target for automatic radar tracking (i.e., automatically follow the target as its location changes with respect to own ship).

The computer (depending on the specific system) may be either an electromechanical or an electronic-electromechanical unit. It accepts all ballistic factors (including I.V.) as well as target data and data on own-ship course and

53.114

Figure 6-15.—Elements of a linear-rate gun fire control system aboard a destroyer.

speed. It transmits gun position data to the gun mounts it controls. And it can send its fire control solution to the director as electrical signals that position the director optical and radar elements to indicate how accurately it is solving the fire control problem. The computer contains no gyroscopic elements.

The stable element contains a gyroscope which, because it remains fixed in attitude, generates a stabilized reference plane to which all angular values received and computed can be related.

The data transmission receivers in the gun mounts control the gun power drives so that the guns will be positioned in accordance with the signals transmitted from the computer.

Relative-Rate Systems

The essential parts of a simple relative-rate fire control system are a director and a transmission system through which the gun position data required for accurate firing are transmitted to the gun mount. In simpler systems, there may be one director for one or two mounts, and the directors are located fairly close to the mounts they control. Range is either estimated optically and cranked in manually, or measured by radar. The director operator looks through the optical sight on the director (or he may use radar) and tracks the target (that is, as it moves in his field of vision he keeps it aligned with his LOS as indicated by a reticule in the sight, or in the center of his radar display). This movement affects a gyroscope and a pendulum device in the director case. Electrical pickup devices in the director sense the gyro and pendulum movements, and send electrical signals to the gun mounts. The signals correspond to the gun positions required for hitting the target, and they either control the mount power drive so that the guns assume the desired positions, or the gun crews may control gun position manually in accordance with the signals as displayed on dials. Simple relative-rate systems take into account only a few ballistic factors—generally gravity, drift, and air resistance.

In some types of relative-rate systems the director may be divorced from the gyro and pendulum devices. The gyro is then a component in a separate computer. The more complex relative-rate systems will accept additional ballistic data inputs and are more accurate, particularly at longer ranges, than the simpler systems.

The most elaborate systems utilize power-driven directors rather than the manually operated directors of the simple system described above. Under radar control, these can track targets automatically once they are "locked on." The more complex systems also include an additional gyro for stabilization, like the one described earlier for linear-rate systems, and additional computers for wind data inputs and for generation of gun positioning signals for two gun batteries simultaneously.

On-mount fire control elements include data transmission receivers, the power drives, and the sights. (In some systems, radar elements may also be installed on the mount.) The first two of these have been discussed in chapter 3; we shall briefly concentrate on the sights. These are optical devices, either telescopic or nontelescopic, equipped with crosshairs intersecting at right angles in the center of the view field. Any target as seen through the sight at the center of the view field is on the line of sight (LOS). Sight dials on the mount indicate at all times precisely the angle that the LOS makes with the axis of the gun's bore. In most mounts, dials concentric with the sight dials and driven by data receivers controlled by the computer are automatically positioned to display the angles that the gun bore axis should make with the LOS if the gun is to be laid for hitting the target. A crewman can manually crank the desired angles into the sight-setting indicator (an indicator with gearing which positions the sights). These arrangements permit continuous aiming of the gun even if the gun power drives quit, if the data transmission from the computer is interrupted, or if the computer or other fire control system elements are knocked out.

SOLVING THE FIRE CONTROL PROBLEM

As you remember from the beginning of this section, the fire control problem consists essentially of three groups of variables. In a given fire control system, some individual variables may either be taken into account or neglected, depending chiefly on target velocity (with respect to own ship) and range, and on desired accuracy and speed of solution. The main steps in solving the fire control problem are:

1. MEASUREMENT of each of the variables to be taken into account.
2. COMPUTATION of what gun position must be in relation to an LOS from own ship to target so that the projectile will hit the target, and transmission of this information to the gun mounts. (This computation and transmission may also include projectile fuze setting if required.)
3. POSITIONING THE GUNS in accordance with this information and energizing firing circuits as required.
4. OBSERVATION of effects of firing and correction of fire control information.

Now consider each of the steps in somewhat more detail.

Measuring or Establishing Values of Variables

Ideally, each variable in the fire control problem should be observed and accurately measured, then entered in the computing system. As a practical matter, some may be estimated and "cranked in" (i.e., put into the system manually), and some may be considered as having a fixed relationship to another variable (for example, the effect of gravity has such a relationship to time of flight), so that they don't have to be measured. (We have already noted that in all but the most refined systems some variables are omitted entirely because they are not considered essential to a solution of practical accuracy.)

1. Ballistic variables are measured and entered into the fire control system computer as I.V. Most of these variables were discussed earlier in this chapter. For a detailed discussion of how I.V. is determined, refer to appendix II.
2. Gravity has a fixed relationship to the time of flight, which in turn has a known relationship to range. Its effect is therefore "built into" the computer as a specially shaped cam (in electromechanical computers) or electrical network (in electronic computers).
3. Air resistance is in most medium- and long-range systems determined by fire control personnel who plot observed air temperature and barometric pressure on a nomogram and then determine the required correction. (Air density correction nomograms are printed in range tables. A specimen is reproduced in appendix II, which also contains details on how this and several other ballistic corrections are determined.) The correction is put into the computer as part of I.V.
4. Wind is a factor in medium- and long-range systems; it is generally neglected in simple relative-rate systems designed for use

at short ranges. In long- and medium-range systems ballistic wind is cranked into the computer.

5. Drift is treated like gravity.

6. Earth's rotation and curvature are figured from range tables and their effects are cranked into the system as direct increments to sight angle and deflection. The computer does not solve for these. In any case, these values are used only against surface targets at extreme ranges. See appendix II for details.

Target position and relative motion of target and own ship are important factors in all gun fire control systems, but for high-speed targets at shorter ranges they dominate the fire control problem.

Target position is fixed by three coordinates—bearing, elevation, and range. All three can be measured optically in a linear-rate system. The first two are established when the sight telescopes in the director are on target. Angular values of director train (an angle nearly equal to relative target bearing) and director elevation (an angle measured with respect to the deck plane, vertically to the LOS) are sent to the fire control system computer by data transmitters (synchros). A linear value of range is measured at the rangefinder and also sent by synchro to the computer.

Radar can be used to measure all three coordinates in a Mk 37 linear-rate system. Data transmission is generally the same when the director is tracking by radar, except that the range synchro information comes from the radar instead of the rangefinder. The Mk 37 (fig. 6-15) is the principal linear rate director used in the Navy. It can track targets optically in train and elevation while maintaining an automatic radar track in range; this is called partial-radar control. Or, either train or elevation can be shifted into automatic radar track without shifting the other, provided the director is radar-tracking in range.

When the director is in full-radar track, the system, including the computing devices, is fully automatic. Sometimes (particularly at long ranges) the target echo is too small for full radar tracking, but can still be seen on the radarscopes in the director. As long as it can be seen, it can be tracked by radar. The pointer and trainer move their power drive controls to keep the target video aligned (in elevation and train, respectively) to the line of sight references on the radarscopes. These references correspond to the actual position of the director in elevation and train, and are aligned to the crosshairs in the optical sights. The radar range operator keeps the target video manually "gated" or aligned to the range measuring device on his radarscope, i.e., the notch, mark, or step as the case may be.

There are several types of relative-rate directors used in the Navy today. Some can track automatically by radar, others track manually by radar, and others use a combination of radar and optical. And then there are the optical relative-rate directors that were installed before radar was used in fire control; these use estimated ranges. One feature common to all relative-rate directors is the use of gyros to measure angular tracking rates. More will be said about this later.

In the simplest relative-rate systems the director operator tends to keep the director stabilized as he tracks the target; in any case stabilization errors in such systems are not important at close ranges with high-speed targets. In longer range relative-rate systems and in all linear-rate systems the system outputs compensate for ship's roll and pitch because they are developed with respect to a stabilized reference plane, which is kept horizontal by a gyroscope. In relative-rate systems the stabilization gyro is incorporated into one of the consoles or into the director of the system; in linear-rate systems the gyro is in a separate console called the stable element or stable vertical. An alternate manual stabilization arrangement used in emergency in some linear-rate systems requires that a crewman sight at the horizon continuously through a telescope coupled to the remainder of the system by a synchro whose output provides the stabilization signal.

Parallax correction is important only in systems where some of the gun mounts are located some distance from the director. A special section of the computer develops parallax correction for a base length (distance between director and gun mount) of 100 yards. This is called the unit parallax correction. For this or any other base length, the closer the target the greater the angular correction needed for parallax. However, the base length assumed for the unit parallax correction is not likely to be correct for any one gun mount, since obviously the parallax correction ought to be greater for mounts further from the director than 100 yards, and less for mounts that are closer. Consequently, there is in each gun mount a set of change gears which converts the unit correction to the correction

required, based on the ratio between the assumed base length and the actual base length. Parallax is also computed to compensate for vertical distance between mounts and director, but since all mounts are more or less equally far below the directors, the computed correction is fed equally to all.

Computation and Data Transmission

This text does not go deeply into the mathematics of the fire control problem and its solution. The details of functioning of a fire control computer will therefore not be described. However, in chapter 3 you learned that such mechanisms as gears, cams, and differentials can be used to perform all the basic arithmetical operations as well as many trigonometric ones. Chapter 3 also described other mechanisms used in a typical fire control computer, such as the integrator, component solver, multiplier, etc. These enable the electromechanical computer, for example, to perform all the mathematical functions necessary in solving the fire control problem.

There are basically three different varieties of computer used in present day Navy gun fire control systems—the GYROSCOPIC, the ELECTROMECHANICAL, and the ELECTRONIC. The first two are what computer engineers call analog computers. The electronic computer may be either analog or digital depending on the system in which it is used. The GFCS (gun fire control system) Mk 68 uses an analog computer (generally) whereas the GFCS Mk 87 uses a digital computer. The difference between analog and digital computation is explained in chapter 3.

GYROSCOPIC COMPUTERS are used in relative-rate systems. They may be housed in gunsight cases which are mounted on directors, or they may be in the director itself. Their function is to generate the correct lead angles, and lead angles (for bearing and elevation) depend on two variables in addition to ballistic corrections. The variables are: (1) the angular velocity of the director or gunsight in bearing and elevation, and (2) the time-of-flight (or range) to the target.

A gyroscopic computer uses a rate-of-turn gyro as shown in figure 6-16A. Assume that the gimbal frame in part A is attached to a gunsight case, and in part B is made to revolve rapidly (and in part C slower) by a motion of the gunsight case while tracking a target. Notice that gyro is restrained by two springs, and in part B the precession is greater than it is in part C.

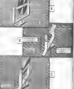


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Figure 6-16.—Functioning of rate-of-turn gyro (simplified). A. Gyro elements. B. Action in tracking fast. C. Action in tracking slowly.

The tension of the two springs is set (either manually or by radar) to be proportional to the target's range. The amount of precession of the gyro, then, is proportional to the angular velocity of the case and the range to the target. As range increases, the tension on the springs decreases. By this action a larger lead angle is developed at longer ranges for a given angular velocity. The springs have another function in that they return the gyro to zero precession when tracking has ceased, and they supply the force to compensate for decreases in angular velocity while tracking.

There are two basic ways to use the rate-of-turn gyro's precession in the fire control system. Older systems use the gyro to control the optical train of the gunsight. The gunsight operator's line of sight is controlled by connecting gyro precession to prisms within the optical train. Since the guns are aligned to the sight case, offsetting the line of sight within the

case introduces the lead angle into the system. The other way to use these data starts is with electrical sensors, called pickoff units. A pickoff unit senses the gyro displacement without perceptibly disturbing it, and produces a proportionate electrical signal. Electrical signals, proportional to lead angles, are sent to the fire control system computer where orders for the guns are computed in some systems. They may also be a direct input to the gun in other systems.

There are various rate-gyro devices in fire control which use one or more gyros. Some use electromagnetic damping devices instead of restraining springs. And some use ballistic gyro sights, while others use torque motors for the ballistic corrections. Discussing all of them in this text would obscure, rather than clarify, the basic theory.

ELECTROMECHANICAL COMPUTERS.—To solve the fire control problem for a moving target, the fire control system must have the rate of target movement with respect to own ship—specifically, the rate of change of target bearing, target elevation, and range. Since own ship is usually in motion also, its motion must be factored into the computer. Own ship's course is transmitted from the ship's gyrocompass, and own ship's speed is transmitted from the pitometer log. Both are synchro-transmitted inputs to the computer. Rates of change in bearing, elevation, and range go into the fire control computer as the director tracks the target. The computer solves the problem by performing a series of mathematical operations with the data put into it. The operations are performed almost entirely by mechanical units of the type described in chapter three. The input data are usually in the form of shaft rotations or other mechanical displacement. The mechanical displacement may be produced either by manually setting a knob or handcrank, or through a servomotor (which reproduces relatively weak electrical or mechanical servoinputs), or a synchro receiver (which reproduces an electrical input without amplification). The computer outputs are mechanical but are translated into electrical synchro signals (with one exception) that go to other system components. The signals are also displayed on dials and other indicators.

In some fire control electromechanical computation equipment, simple computation (addition and subtraction) may be performed by synchro units.

ELECTRONIC COMPUTERS.—Electronic analog fire control computers use specific circuits or electrical elements to perform specific mathematical functions. For example, two voltages can be added or subtracted in an electrical network similar to the one in figure 3-78; if a-c voltages are used, changing their phase relationship yields a voltage that represents the vectorial sum of the voltages. Transformers, both fixed and variable, can be used for multiplication or division—changing the transformer turns ratio changes the divisor. Rotary variable resistors called potentiometers can vary the amount of resistance in a circuit either in straight-line fashion or in accordance with a selected nonlinear function (for example, the effect of drift). Such functions can also be calculated by using special nonlinear amplifier circuits. Small rotary transformers called resolvers can either resolve an a-c voltage representing a vector quantity into its components (for example, yield north-south and east-west components of own-ship course and speed), or add the components to yield a solution expressed in an a-c voltage of specific amplitude and phase, or perform other functions with vectors. In such electronic computers, the shafts of rotary devices such as potentiometers and resolvers (as well as synchros) are usually driven by servomotors energized by servoamplifiers. An electronic analog computer can thus be functionally substituted for an electromechanical one.

By using flip-flops, storage registers, and other digital devices, digital fire control computers can perform the same operations as analog computers.

DATA TRANSMISSION.—Except for mechanical connections between computer and the stable element in some linear-rate systems, all data transmission between fire control system elements is through synchro systems. These were explained in principle in chapter 3. All inputs and outputs between systems are translated into synchro signals of transmission and retranslated into suitable electrical and mechanical outputs at the receiving end.

Thus, for example, the signal voltage developed by a pickoff unit on a train rate-of-turn gyro in a relative-rate director controls a servo whose motor drives a synchro transmitter. The transmitter's output goes through synchro wiring to the gun mounts.

The data transmitted electrically by synchro to the gun mounts from the fire control system

include at the minimum, gun train and elevation orders. In some relative-rate systems no other data are transmitted; in others, and in linear-rate systems, transmitted data may include sight angle, sight deflection, fuze-setting order, and parallax.

POSITIONING AND FIRING THE GUN

With the fire control problem's variables evaluated and the solution available, it is possible to lay the gun so that the projectile will hit the target. Other requirements may limit the solution in such a way that firing can successfully take place only at certain instants, in which case the solution must specify those instants.

The process of gunlaying is essentially that of offsetting the axis of the gun bore from the LOS by a specific angle. This compensates for the divergence of the trajectory from the straight line it ideally would be in interstellar space with stationary gun and target. No matter what any specific variable in the gun fire control problem may be or what its magnitude and direction are, the only possible ways of compensating for it are (a) variation in the propelling charge or projectile (which for all practical purposes is so infrequently done that we can neglect it here) or (b) algebraically adding an increment in the angular offset between gun bore axis and the line of sight (the only method we consider in this chapter). Since the gun is positioned in two perpendicular planes by its train and elevation mechanisms, the offset is always measured in two perpendicular planes.

Figure 6-17 shows the angular offsets for a surface target. The vertical offset in part A is called SIGHT ANGLE; the deflection offset in part B, SIGHT DEFLECTION. These two angles are equal to the total lead angles for elevation and bearing in both air and surface exercises. In a surface exercise, the elevation lead angle assumes the properties of a "range lead angle" since range is a function of the gun's angle of elevation. Smaller angular values make up sight angle and sight deflection. For example, drift is part of sight deflection and an angle called SUPERELEVATION is part of sight angle. Superelevation is the angle that the gun must be elevated above the line of sight to compensate for the downward pull of gravity. It is not affected by the relative motion of own ship and target; but it is affected by range and elevation, the variables which cause changes in trajectory. Thus the required superelevation, at any given range, is determined by the uncorrected trajectory. If own ship and target in figure 6-17A are stationary, and if wind effects are discounted, then superelevation will equal sight angle.

Figure 6-18 shows the vertical offset for an incoming air target. Notice that the LOS to target is elevated above the horizontal by an angle labeled target elevation. The gun barrel is elevated above the LOS by sight angle. Sight angle here not only includes a correction for superelevation, but predictions based on relative motion as well.

The angles which ultimately position the gun are called GUN ELEVATION ORDER and GUN TRAIN ORDER. Essentially, each contains an angle equal to target position in elevation and bearing, respectively, plus the computed lead angle for each. Since a gun elevates and trains in the ship's deck plane, gun elevation order is the amount the gun is elevated above the deck plane, and gun train order is the amount the gun trains in the deck plane measured clockwise from the ship's bow. Gun train and elevation orders are outputs from the system computer, and their principle computed variables, respectively, are sight deflection and sight angle.

Now consider the effects of fire control variables on sight angle and sight deflection, and on elevation and train gun orders of which they are part.

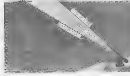
Ballistic Variables

In the following list of ballistic variables, we indicate the effect that increasing the variable has on sight angle and sight deflection.

Variable	How compensated as variable increases
Projectile momentum	
(a) Mass (weight)	Increase sight angle.
(b) I.V.[1]	Decrease sight angle.
Gravity (itself a constant, but its effect is a function of time of flight).	Increase sight angle with increased time of flight.
Air resistance	Increase sight angle.

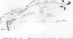
[1] In practice, as the gun wears I.V. decreases, hence sight angle must be increased to compensate.

A



B

Figure 6-17.—Offsets from LOS. A. Sight angle. B. Sight deflection. 84.198



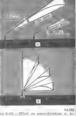
84.201
Figure 6-18.—Target elevation and sight angle.

Wind....................	Depends on wind direction. If wind tends to increase range, reduce sight angle (and vice versa); add deflection and sight angle as needed for cross winds.
Drift....................	Add left deflection.
Earth's rotation and curvature............	Varies with range, latitude of gun, gun bearing. Both sight angle and deflection may be affected.

Correction for Target Position and Target Motion

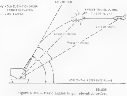
If you consider both your ship and the target to be stationary, once you know target position (bearing and range) you need lay the gun only for ballistic and wind corrections to put your projectiles on target. For a stationary air target you would have to add target elevation to the problem. Figure 6-19A shows superelevation angle to be large for a given target elevation at long ranges. But notice what figure 6-19B shows. Assuming a constant slant range, superelevation gets smaller as the target elevation increases. Superelevation is zero when the target is directly overhead (090° elevation). To put it precisely, superelevation varies directly as the cosine of target elevation.

Now let us look at a moving target as in figure 6-20. This figure only shows the basic elements in gun elevation order. Notice that the ship's deck is assumed to be horizontal (rarely

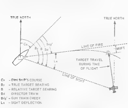


84.202
Figure 6-19.—Effect on superelevation: A. Increased range. B. Increased target elevation.

is this true) and that superelevation is not shown in the figure. You will recall that superelevation is a part of sight angle. Figure 6-21 shows the relationship of the various angles in gun train order. These angles are easily understood. However, we will discuss two items which may be new to you. First, notice that relative target bearing (B) and director train (Bd) are shown as equal angles. This is true only when the ship's deck plane is in the true horizontal (when there is no roll or pitch). Director train is measured in the deck plane, and relative target bearing is measured in the horizontal plane. All of the other quantities, except for gun train order, are measured in the horizontal plane. The second item concerns sight deflection (Ls). Sight deflection corrects for projectile drift and for the target's travel during the projectile



55.228
Figure 6-20.—Basic angles in gun elevation order.



55.229
Figure 6-21.—Basic angles in gun train order.

time of flight. The correction in our illustration is in the same direction for both factors. If the target were proceeding on an opposite course, sight deflection would be the algebraic sum of the corrections for drift and the target's travel during time of flight because the drift correction is always to the left. In the situation shown in figure 6-21, the gun train order angle (Bdg') is less than the director train angle by the amount of the sight deflection angle. (There are various other angles in fire control, which have been omitted for simplicity in figures 6-20 and 6-21.)

Inherent Corrections

As you remember from an earlier discussion, inherent corrections are (a) correction for motion of the gun platform, (b) parallax correction, and (c) roller path compensation.

We correct for motion of the gun platform (i.e., ship's pitch and roll) by relating it to a gyrostabilized horizontal reference. You may recall from chapter 3 that one of a gyroscope's characteristics is its tendency to maintain a stable attitude in space (the other, used in gyroscopic computers, is its tendency to precess when the direction of its shaft is changed). In different gun fire control systems the gyroscopic mechanism that does this is called a stable element, a stable vertical, or a vertical gyro, but the principle is the same. The gyro maintains a fixed vertical attitude; electrical pickoff units (which roll and pitch with the ship) continuously sense their angular displacement with respect to the stable gyro axis and produce a corresponding signal. The gyro unit receives director train angle as an input; its main outputs are level angle and crosslevel angle. Figure 6-11 shows level and crosslevel.

These quantities are combined in the computer along with the ballistic and target movement (lead) corrections to make up sight angle and deflection; these, in turn, become part of the gun orders to the mounts.

Horizontal parallax corrections, as pointed out earlier in this section, are computed on the basis of a standard unit correction which is then converted at each gun mount to the proper value for that mount. Horizontal parallax correction is usually transmitted independently of gun order to the gun mounts. Vertical parallax is considered equally applicable to all mounts, since their height variations are small, and is transmitted as part of sight angle.

Roller path correction is taken care of entirely by the mount compensator mechanisms mentioned earlier.

How the Guns are Positioned

In most mounts larger than 20-mm, the guns are positioned by electric or electric hydraulic power drives. They may be positioned by automatic control (i.e., by the power drives under the complete remote control of the computer or director), in local control (by the power drives under the control of the mount crew), in manual control (by the muscular effort of the mount crew), or in hand control (in some 5-inch electric-hydraulic mounts only; the hydraulic elements of the power drive are directly controlled by the crew). Automatic control is the primary mode of control; the other modes are used either in mount adjustment or for emergencies and in training for emergencies.

As they come from the synchro transmission wiring, the gun order signals are fed to an indicator-regulator or a receiver-regulator. These perform pretty much the same function; they are the control element of the power drive (which, as you recollect from chapter 3, is fundamentally a servomechanism). The distinction between indicator-regulators and receiver-regulators is not significant functionally. From here on we will refer to all of them as indicator-regulators. Naturally there is a separate indicator-regulator for the train power drive and for the elevation power drive in each mount.

The gun order synchro signal is usually dual-speed; that is, it consists of two separate signals, one low-speed (coarse) and one high-speed (fine). (These were explained in chapter 3.) The coarse signal is generally 1-speed (i.e., synchro rotation bears a 1:1 ratio to the value being transmitted), though in some systems a 2-speed coarse signal is used for elevation (i.e., synchro rotation bears a 2:1 ratio to the value being transmitted, so that, for example, synchro rotation of 200 minutes occurs when an elevation value of 100 minutes is transmitted). In today's standard practice, the high-speed signal is 36 times the low-speed signal (i.e., the fine synchro rotor turns 360° fo each 10° rotation of the coarse synchro rotor). In most synchro dual-speed transmissions, the fine synchro signal is then a 36-speed signal; in those with a 2-speed coarse signal, the fine signal is 72-speed.

Indicator-regulators now in service in gun mounts (other than bag-type major-caliber turrets, which we do not take up here) can be classified in the following general types:

1. Those with a hydraulic amplifier controlling a hydraulic A-end.
2. Those with an electronic amplifier controlling a hydraulic A-end.
3. Those with an electronic amplifier controlling an electric drive.

Most 5"/38 mounts with power drives have the first type of indicator-regulator. The incoming gun order signal goes into synchro receivers; their rotors turn and actuate sensitive hydraulic pistons which control oil flow to more powerful pistons; these position the A-end tilt plate so that the B-end drives the mount in accordance with the signal. Mechanical feedback drives the synchro stators to null position.

The second type of indicator-regulator (or receiver-regulator) is used in some turrets, in late type automatically loaded 5"/54 mounts, and in 40-mm mounts. In this type the incoming synchro signal goes to synchro control transformers which convert it into an a-c voltage whose phase and magnitude are proportional to the angle of the synchro control transformer rotors with respect to their stators. This a-c voltage is then fed into an amplifier. (In dual-speed systems, an electrical "synchronizing network" feeds the sum of the two rotor signals to the amplifier, but it disconnects or suppresses most of the fine synchro output if the gun deviates from gun order position by more than a few degrees.) The amplifier may be of the conventional vacuum-tube type, it may use transistors instead of tubes, or it may combine a tube or transistor preamplifier with a magnetic amplifier. Its output drives a motor, which regulates a pilot piston that positions or controls the position of the hydraulic A-end. The remainder of the cycle (including mechanical feedback to the synchro control transformers) is similar to the first type described.

In the third type, synchro control transformers, synchronizing networks, and amplifiers function as in the second type, but the amplifier output goes to an amplidyne drive system (something like an electrical A-end and B-end) described in chapter 3. Again, mechanical response drives the synchro stators to null.

How the Guns are Fired

Fire control does not end with control of gun aim. It also includes control of actual firing. This means initiating the firing impulse and originating (or relaying) the operational commands to gun crews. Generally, when a power drive is to be controlled automatically by a gun director or a plotting room (plot), its firing circuit is activated by whichever station is in control. Antiaircraft batteries are normally always fired by their respective directors. A dual-purpose battery is fired from either its director or the stable element in the plotting room, depending on the type of firing engagement and whether direct or indirect aiming is required. A general rule here is that when indirect-fire is used (i.e., the LOS is established by the use of maps and charts in the plotting room), firing is controlled by plot. (Indirect-fire is used only against shore targets.) This general rule works for a surface battery too, when it is engaged against shore targets or perhaps aircraft.

Surface fire against waterborne targets is just a little different. A surface target has a zero elevation angle, which means that the director pointer (the crewman who normally measures elevation) can be released from establishing the LOS in elevation. The required gun elevation is automatically established when the correct value of range is set into the computer. (Other switching at the computer is necessary but will not be discussed here.) In this setup the pointer will not know when the system is on target, so control of firing is from the stable element in plot. The stable element was selected because it is the only device in the system capable of measuring the two remaining variables in the problem — roll and pitch. The director measured bearing and range, and when compared to roll and pitch they are nearly constant; or at least predictable. We can assume that the system will be on target in bearing and range at the instant of firing.

Most of the time the followup devices in the stable element will be in automatic. This mode provides continuous measurement of level and crosslevel which are then sent automatically to the computer. Since level and crosslevel become part of the gun orders, the guns are stabilized regardless of the ship's roll and pitch. If the firing selector switch on the stable element is in the "continuous" position, and if the level and crosslevel followups are in automatic, the guns can be fired at any time during ship's roll and

pitch by closing a hand firing key on the stable element. The hand firing key is not electrically dependent on the followups, but it wouldn't be closed until level and crosslevel were accurately measured. Level and crosslevel are measured automatically by followups, or manually by handcranks. The latter method is used in emergencies for continuous measurement in case the followups become inoperative, and for two other firing modes called selected-level and selected-crosslevel, which we will now discuss.

When the sea is very rough, automatic followups may not be able to provide a continuous, accurate measurement of level and crosslevel. Even if they can, the gun power drive may not be able to keep up with the changing gun order signals. Or, the changes may be so great that they drive the gun into its firing cutout limits opening the firing circuit. Under these sea conditions we could probably increase accuracy by removing the level and crosslevel inputs to the gun orders and allowing the gun to roll and pitch with the ship. At least we would eliminate the chances for error mentioned in this paragraph.

Level or crosslevel, one or the other, will usually have a larger variation, depending on the bearing of the gun and the roll and pitch of the ship. It is usually possible to leave the smaller variable in automatic and depend on its followup. An arbitrary value for the larger is "selected" at the stable element (stable vertical for turrets) and becomes a stationary input to the computer. The selected quantity must permit the gun to be correctly aimed at some point between the observed limits of the ship's roll and pitch; usually about the midpoint. Electrical contacts on the stable element automatically close the firing circuit (if the stable element automatic firing key is closed) at the instant ship rolls or pitches to the selected level, or to the selected crosslevel. The method of fire is chosen by the stable element operator who may operate his firing selector switch to the continuous, selected-level, or to the selected-crosslevel position.

OBSERVATION AND CORRECTION OF FIRE

Although the preceding discussion of fire control has referred often to the desired ideals of accuracy and speed in solution, and has at least hinted (it has not been possible to describe or even to refer to them all) at the refinements in modern fire control systems, it is still true that not all the factors which affect the flight of a projectile can be precisely evaluated in advance of firing. Even with the best fire control equipment available, experienced gun crews, and efficient fire control personnel, the opening shots may not hit the target. It is therefore necessary to apply corrections to the initial firing data. These corrections are called SPOTS.

The initial spot is based on a system analysis of inherent errors. Even though the initial spot is figured precisely, external ballistic factors may still cause projectiles to miss the target. When this happens spots (based on where the rounds hit in respect to the target) are applied to subsequent salvos. Spotting is taken up in further detail in chapter 9 of this text.

SECONDARY METHODS

So far in discussing fire control, we have concentrated on the primary methods of battery operation. These are the ones most commonly used, and the ones which permit employment of the ship's armament with the greatest efficiency. But battle damage, personnel losses, and accidents can disable any system to the extent that some secondary operating methods are essential if the system is to keep operating at all, even if not at full efficiency. Aboard ship you will not only employ such methods in battle operations, but also in training for such emergencies.

All 3" gun mounts and larger are equipped with adjustable sights. With these, it is possible to offset the gun bore axis from the LOS to the desired sight angle and deflection. This function is performed by a crewman called the sightsetter, who mans the sight-setting indicator. In gun mounts 5-inch and larger, this unit contains handcranks and gearing for physically moving the sight optical units (or moving optical parts within the sights), and two sets of dials (fig. 6-22A or 6-22B). One set, driven by the sight gearing, displays present sight angle and deflection. The others are synchro-driven to display sight angle and deflection ordered by the computer. (3"/50 mounts do not have the synchro-driven dials.) Even in automatic operation the sightsetter mans his station and cranks the sight gearing to keep the sight indicator dials matched up with the computer-controlled dials so that the LOS of the gun sights remains on target even though the gun bore axis is offset in accordance with the sight angle and deflection components of gun order. In 3"/50 and 5"/38 mounts, an extra range dial coupled to the sight angle crank reads directly in yards of range to a surface target.

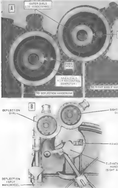


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Figure 6-22.—A. Sight setting component arrangement. B. Sight angle and deflection dials.

In all types of secondary (local) control the gun must be laid by gun-laying personnel on the mount. In older types like 40-mm and 5"/38 mounts the pointer on the left side of the mount elevates and depresses the gun while the trainer (on the right) trains the mount. Each gun layer has a gun sight. They may either control the mount power drive or position the mount by their own muscular effort (manual operation).

In 3"/50 RF (rapid-fire) mounts, and automatically loaded 5"/54 mounts, there is no provision for completely manual operation. The mount can be operated in local, but only if the power drive is functioning. Manual operation is limited only to maintenance and stowing movements, in such mounts, either of the gun layers can take over complete local control of gun positioning.

In local control, gun layers must work with the sightsetter. Here is the basic procedure:

1. The gun layers position the mount so that their lines of sight are on target, and they continue positioning it to keep on target.

2. Most mounts have synchro-driven dials, as in figure 6-22A, which indicate computed sight angle and deflection. The sightsetter cranks in sight angle and deflection until the outer dials (positioned by his handcranks) match the inner (synchro-driven) dials. This action simultaneously repositions prisms in the sight optical systems, causing the telescope lines of sight to shift off target.

3. The gun layers drive the mount to keep on target. This automatically offsets the gun bore axis by the angles that the sightsetter has cranked in.

Figure 6-22B shows the handcrank arrangement; figure 6-22A shows in more detail how the dials look when matched. The fixed index shows the angular values actually cranked in. It is used when there is no synchro transmission; under these conditions, the information is either transmitted by phone or comes from the mount captain, based on his estimate of range, ballistic corrections, and lead.

On mounts 5-inch and larger, the sights are carriage mounted. The sights therefore train with the carriage, but the carriage doesn't elevate. To make the sights elevate with the gun, they must be driven by a mechanical linkage from the elevating gear. Thus the sight angle prisms in the optical systems must be positioned by the algebraic sum of two inputs—gun elevation and sight angle. This is the function of a mechanical differential in the sight angle gear train.

Mounts smaller than 5-inch have side-mounted sights, which elevate and train with the gun barrel. The differential is not needed. Nor do mounts smaller than 5-inch have synchro receivers for sight angle and deflection. When necessary, computed sight values are transmitted by phone.

When the gun bore axis offset is correct, the gun layers have been staying on target, and the gun is loaded, the gun can be fired by the pointer's firing key. This may be done on the mount captain's command. In the complete absence of firing current or if the ammunition fails to fire electrically, some 5-inch guns can be fired by percussion when the pointer depresses a firing pedal, which actuates a mechanical linkage to the firing mechanism. Combination primers in the ammunition are necessary to provide this capability.

Secondary methods used in the director and in fire control plot are limited. In earlier linear-rate fire control systems, the director can be driven manually in the event of power drive failure. This is not true in newer systems; manual operation is used in storing the director or in maintenance only. If synchro transmission fails, range, bearing, and elevation data can be sent to plot by sound powered telephone, as can firing orders to the mount if the firing circuit fails. In the event of stable element failure, some older fire control systems can be stabilized manually by a crewman who keeps a telescope's line of sight aligned with the horizon. If synchro transmission fails with any computer inputs or outputs, data can be introduced manually or read from dials and telephoned from plot, but neither stable element nor computer can function without the proper supply. When any failure prevents data from reaching the gun mount, secondary methods must be used at the gun mount.

LINEAR-RATE FIRE CONTROL SYSTEMS

Gun fire control systems can be, on the basis of their fundamentals of operation, divided into

two main classes—linear-rate and relative-rate, as explained earlier in this chapter. There are several marks and mods of linear-rate systems, including two dual purpose types—the Mk 37 and the Mk 68. The main difference between these two is that the Mk 37 uses the Mk 1A electromechanical analog computer, whereas the Mk 68 system uses an electronic analog computer, and it is capable of tracking targets traveling at supersonic speeds.

GUN FIRE CONTROL SYSTEM MK 37

The Gun Fire Control System (GFCS) Mk 37 is installed in some destroyers, cruisers, carriers, and large auxiliaries. It is the primary means of controlling 5"/38 mounts for both surface and antiaircraft fire. It may be used, with appropriate cross connections, to control machinegun mounts, or major-caliber surface guns in special applications.

System Functions and Components

The primary functions of the Mk 37 GFCS are to provide:

1. Continuous automatic gun positioning.
2. Continuous automatic fuse setting.
3. Continuous sight-angle and sight-deflection indication at the guns.
4. Continuous-aim, selected-level, and selected-crosslevel fire.
5. Star shell fire control.

A complete system consists of three major units: a Mk 37 director with a radar; a Mk 6 stable element; and a Mk 1A computer, with the associated instruments at the gun. Destroyers and auxiliaries having Mk 37 systems carry one complete system (fig. 6-23). Larger ships (such as cruisers and carriers) may have more than one system.

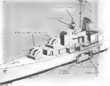

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Figure 6-23.—Mk 37 system, destroyer installation.

Directors are installed high in the ship's structure, and stable elements and computers are installed below decks in protected plotting rooms. All elements are connected by a synchro transmission system through one or more switchboards located in plotting rooms.

Normally, each director in a multiple installation controls a designated group of guns and is connected to a designated computer. However, switching arrangements permit any director to control any or all guns and connect to any computer.

Information Flow

Figure 6-24 is a simplified schematic showing the principal interconnections of a single Gun Fire Control System Mk 37. All electrical circuits between units of the system pass through the fire control switchboard.

The director carries sight telescopes and a rangefinder and radar equipment to measure and transmit to the computer director elevation, director train, and present range. The control officer in the director may estimate target angle, target horizontal speed, and rate of climb or dive and send these values by telephone to the computer operators. Hand-operated transmitters in the director provide electrical transmission of elevation, deflection, and range spots (i.e., observed corrections) to the computer.

The stable element receives director train from the computer and measures level angle and crosslevel angle. These values are sent mechanically to the computer. A third value, level plus crosslevel divided by thirty, is transmitted from the stable element to the computer to make up a LOS stabilization signal to be transmitted to the director. Other electrical inputs to the computer include own-ship course from the gyro compass and own-ship speed from the ship speed sensor. Lastly, computer personnel add manual inputs as required.

The computer transmits electrically to the gun mount:

1. Gun elevation order.
2. Gun train order.
3. Sight angle.
4. Sight deflection.
5. Fuze-setting order.
6. Train parallax for a 100-yard horizontal base.

These values are used for gun positioning, sightsetting, and fuze setting.

In addition, the computer generates and transmits to the director changes in range, elevation, and train. With level and cross-level, these changes are used to hold the director optics and radar on the target continuously. This process includes keeping the rangefinder and radar on the target.

The Mk 37 Director

The Mk 37 director is designed, primarily, to control 5"/38 dual purpose guns. Its primary function is to determine target position in terms of:

1. DIRECTOR TRAIN—the angle between the fore-and-aft axis and the vertical plane containing the line of sight, measured in the deck plane clockwise from the bow of the ship.

2. DIRECTOR ELEVATION—the elevation of the director's line of sight above the reference plane, measured in the vertical plane containing the line of sight.

3. PRESENT RANGE—the distance of the target from own ship, measured in the line of sight.

Briefly stated, the director's secondary function is to be the control station for the entire fire control system. Normally, all units operate by remote control from the director, and as long as the problem is being solved correctly, only the gun-loading crews have work to do. The remainder of the crew simply observe operations to insure that everything is operating correctly. When changes in the problem setup are necessary, the director crew can accomplish them by remote control. To control the entire system, the director is equipped to do the following:

a. Spot service projectile fire.
b. Spot illuminating projectile (star-shell) fire.
c. Correct computer calculations.

CONSTRUCTION.—The director (fig. 6-25) is an armored steel box that can be trained (much like a gun mount) on a precision-aligned roller path mounted on an armored cylindrical barbette built into the ship's structure. It contains an optical rangefinder and pointer's and trainer's prismatic telescopes, radar equipment, power drives for positioning the director, an observation hatch used by a control officer (who may

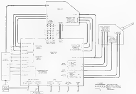

Figure 5-24. — Data flow in Mk 37 GFCS. Simplified schematic (Star shell data omitted.)

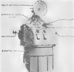

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Figure 6-25. — Gun director Mk 37.

also serve as a spotter), and a slewing sight for positioning the director to pick up the target.

GENERAL OPERATION. — The line of sight is kept on the target in train by turning the entire director on its roller path. The angle the director turns from the centerline of the ship is director train. Rotating the telescope prisms, the radar antenna and rangefinder, elevates the line of sight to give director elevation.

Train and elevation of the director line of sight can be done in four modes:

1. AUTOMATIC (or remote) control of the power drives by signals from the computer, modified as necessary by the handwheels.

2. LOCAL operation of the power drive by means of the handwheels.

3. MANUAL operation by direct gearing from the handwheels.

4. SLEWING or training and elevating rapidly to change targets.

The rangefinder determines range optically. The rangefinder operator can adjust the apparent position of the "wander marks" with relation to the target in the rangefinder field of view. This adjustment is transmitted by synchro to the computer as a range signal. The computer generates change-of-range signals that are fed back to and control rangefinder adjustment.

Radar is used for target acquisition and tracking, as explained later. It also provides for automatic tracking.

STABILIZATION. — Director optics and the radar antenna are stabilized both in level and crosslevel. Stabilization in level is discussed below. Crosslevel stabilization is done by a servo controlled by a crosslevel synchro signal received directly from the stable element (fig. 6-26). The crosslevel servo motor is connected to the telescopes, rangefinder, slewing sight, and radar antenna. The crosslevel drive rotates the telescopes, the whole rangefinder, and the radar antenna about the line of sight by the amount of

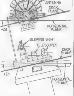

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Figure 6-26. — Crosslevel stabilization.

the crosslevel angle. Thus the telescope crosshairs, the rangefinder, and the radar antenna are kept horizontal, so that director elevation is measured in the vertical plane.

TRAIN, ELEVATION, AND SLEWING CONTROL.—This discussion is chiefly concerned with automatic optical control of the director. Automatic operation in regard to data transmission is similar for radar and optical track; radar will be discussed later. We begin our discussion with optical track operation.

Initially, the target is acquired by slewing the director to the target by use of the slewing sight. The slewing sight can drive the director to the target at a maximum rate of speed; much faster than speeds generated by the pointer and trainer handwheels. The slewsight also has a much wider field of vision than is available through the pointer and trainer optics. When the slewsight is on target, the pointer, trainer, and rangefinder operator should see the target in their optics. They then take over and provide more accurate tracking of the target. During the tracking process, director train, director elevation, and range (and any changes thereto) are automatically fed into the Mk 1A computer. Computer solution time can be shortened if the director officer telephones estimated values of target angle, target speed, and target rate of climb or dive to the plotting room. But, the computer can solve the fire control problem without these estimates, and that is most often the case. When the computer starts generating a solution, it transmits computed (generated) corrections to the director keeping it on target as long as the solution remains correct.

Computed bearing correction consists of increments of computed change in director train, including changes in train caused by relative target motion, changes in own ship's course, and the effect of deck tilt. If computed bearing correction is correct, the line of sight stays on target without handwheel motion.

If the director while in automatic tends to drift off target, the trainer can, by closing the rate control key and keeping the line of sight on target with his handwheels, introduce a correction into the computer. This is necessary if there is a change in target course or speed. If the target becomes obscured, the trainer allows computed bearing correction to continue to drive the director until the target reappears.

Rate controlling also can be accomplished by the computer operator.

The description of train control applies generally in elevation control. The telescope prisms rotate; the rangefinder rotates about its longitudinal axis; and the radar antenna rotates about its mounting to follow the target in elevation. Now director elevation is the sum of target elevation and level angle. To hold the LOS on target, in elevation, director elevation must be changed by adding increments of generated elevation and continuous corrections in the value of level. These are received from the computer and are fed to the sights, rangefinder, and radar, so that the LOS is stabilized in level as it tracks the target.

To shift from one target to another or to make any other large change in elevation and train, the director officer may slew the director. He does this by operating a key on the slewing sight and pointing the sight at the target. This takes away control of the director from the pointer and trainer, and drives the director at high speed until its line of sight coincides with that of the slewing sight. Slewing brings the target into the fields of the optics, and thus designates the target to the director crew.

RANGE CONTROL AND SPOT TRANSMISSION.—The rangefinder's optical elements and range synchro transmitter are adjusted for range by a differential, which accepts inputs both from the operator's knob and from a servo controlled by a generated range signal from the computer. Thus the rangefinder operator can correct the rangefinder adjustment and transmit an accurate value of observed present range. He also can rate control the system by pressing a button and operating his range knob, as explained in connection with train operation.

The rangefinder operator has a transmitter for sending spots in range to the computer. The director control officer has a transmitter for sending bearing and elevation spots to the computer.

RADAR.—The automatic-tracking fire control radar has its antenna and parabolic reflector mounted atop the director, with indicator scopes and other components in the director and below decks. This radar has three types of antenna scan; spiral for target acquisition, conical for tracking, and circle for spotting shell splashes in surface fire.

Normally, the automatic tracking feature makes rate control corrections unnecessary. Tracking signals—representing target range, bearing, and elevation—are generated from radar

information and compared with generated range, bearing, and elevation. Differences between computed and radar values are transmitted to the director as corrections, to reposition it in accordance with the radar information, and to the computer to correct its solution until it matches the radar values. Once the target has been acquired by radar, this process is continuous and automatic.

DIRECTOR CREW.—The director is normally manned by five men: a control officer, pointer, trainer, radar operator, and rangefinder operator.

The control officer is in charge of the entire system when the director is in control. In addition to his mechanical functions of accepting target designation from the designating station, slewing the director, and making spots, the control officer must originate battle orders for the battery, relay orders and information from the weapons control station, and generally oversee the operation of his battery. A complete and detailed understanding of all standard commands, procedures, and safety requisites is essential.

The pointer and trainer keep the director line of sight on target in optical tracking; they rate control as necessary. Each has a firing key that can be selected to control the firing circuit, although the pointer is most often in control. In radar tracking, the pointer and trainer cause the system to shift into full-radar track by kicking foot switches when they are on target as viewed on their radarscopes. Or, by moving their power drive handwheels and watching their radarscopes, they can keep target video positioned and thereby provide an alternate method of radar tracking. The pointer and trainer also operate special handcranks which move the director in train and elevation when searching for the target around the designated target position.

The rangefinder operator mans the rangefinder, may spot in range and deflection, and may rate control in range. When the rangefinder is not used, he assists the radar operator.

The radar operator controls the operation of the radar, supervises the pointer and trainer in their use of elevation and train radarscopes, operates the radar in range, and assists the rangefinder operator when radar is not in use.

The Computer Mk 1A

The computer Mk 1A is the mechanical brain of the GFCS Mk 37. It computes continuous gun orders, which contain all significant factors that affect fire.

The gun orders, fuze-setting order, and parallax corrections are continuously transmitted from the computer to the gun mounts, where they are used to point the guns continuously, and to time fuzes so that the projectiles will explode at the predicted target position.

The computer is built in four sections: control section, indicator section, computer section, and corrector section. The first two are mounted on top of the second two, as shown in figure 6-27. The star shell computer, an independent unit, is mounted atop the main computer.

The control section contains the mechanisms for computing and controlling rates. This section has most of the knobs, cranks, and dials. The computer section contains the mechanisms used to calculate ballistics. The indicator section displays, on dials and counters, the results of ballistic calculations—sight angle, sight deflection, fuze order, and advance range. The corrector unit computes and indicates gun train order, gun elevation order, and parallax.

The computer's functions are:

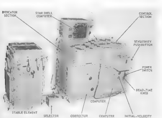
1. To control continuously the positioning of dual purpose guns and the setting of fuzes and sights for either AA or surface fire.

2. To aid the director crew in keeping the line of sight on target.

3. With the star shell computer, to permit part of the dual purpose battery to be set continuously for illumination of a surface target while firing other mounts at the target in the usual manner.

STAR SHELL COMPUTER.—The star shell computer is an independent accessory with which it is possible to direct the fire of one mount for illuminating a target or target area while the rest of the battery, under the control of the main computer, fires for effect. The mount controlled by the star shell computer uses illuminating projectiles (colloquially called STAR SHELLS) that are aimed and time-fuzed to burst above the target.

OUTPUTS AND INPUTS.—Figure 6-24 shows schematically the outputs and inputs of the Mk 1A computer. Note the distinction between electrical synchro signals, electrical signals (used in



51.103;83.105
Figure 6-27.—Mk 1A computer and Mk 6 stable element.

rate control) that are not synchro signals, mechanical inputs and outputs (between computer and stable element), and inputs manually introduced.

COMPUTATIONS PERFORMED AND FEEDBACK EFFECT.—The computer reckons relative target motion rates, which are used in generating changes in target range, bearing, and elevation. Changes in own ship's course are taken into account in computing changes in target bearing. Because rangefinder ranges are often somewhat erratic, the computer uses generated range for its calculations, to improve smoothness of operation. Measured relative target bearing and target elevation are used because they can be measured accurately and smoothly. Target elevation is obtained by subtracting level from director elevation. Relative target bearing is obtained by adding deck-tilt correction to director train.

The computer generates increments of range, relative bearing, and elevation. Increments of relative bearing is sent to the director train receiver-regulator to position the line of sight according to the generated value of director train. It takes into account both deck-tilt correction and changes of own ship's course. Thus, if the solution is correct, bearing correction will keep the line of sight on the target in train while the ship rolls, pitches, and changes course.

Increments of elevation are added—in the computer—to the level plus crosslevel function quantity. The sum, called elevation correction, controls the director elevation power drive to

hold the LOS on target in elevation, if the computer solution is correct.

The changes in director train and elevation from bearing and elevation corrections show up in the new values of director train and elevation. Thus there is a continuous feedback into the computer, since the director continuously transmits director train and elevation to the computer. The computer and director together from a regenerative system. This allows the director to follow an obscured target by riding the computer solution; as long as the solution is correct, the director will remain on target.

Wind computations are made empirically. Air-density corrections are computed separately and applied to the computer as a change in initial velocity. Initial velocity settings are otherwise based on equivalent service round (E.S.R.) data—explained in chapter 5.

The quantities considered in the computation of sight angle, sight deflection, and fuze setting are:

Sight angle

1. Elevation prediction.
2. Superelevation.
3. Wind elevation correction.
4. Initial velocity elevation correction.
5. Complementary error.
6. Elevation parallax correction.
7. Elevation spot.

Sight deflection

1. Deflection prediction.
2. Drift.
3. Wind deflection correction.
4. Deflection spot.

Fuze setting

1. Time of flight.
2. Dead time.

The details of rate controlling are not discussed in this text. They are found in OP 1064.

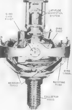
COMPUTER CREW.—The full operating crew for the computer consists of a range operator, a bearing operator, an elevation operator, and a star shell computer operator. In addition, a stable element operator and a switchboard operator are required for each computer-stable element combination.

The Mk 6 Stable Element

The Mk 6 stable element (fig. 6-28) is located in the plotting room next to the Mk 1A computer. In general, its primary function is to measure level angle and crosslevel angle. The stable element does this by using a gyroscope to establish true vertical and true horizontal.

The principal functional elements of the Mk 6 stable element are the sensitive element, the measuring group, the righting system, and the followup system.

SENSITIVE ELEMENT.—The sensitive element is the heart of the stable element; it consists



110.66
Figure 6-28.—The Mk 6 stable element.

of the gyroscope, gyro case, gyro gimbal, and rotating fork (fig. 6-28). The gyro wheel and the ball bearing-mounted axle form the rotor of a high-speed (8500 rpm) induction motor. The gyro assembly pivots within the gyro gimbal on a case axis perpendicular to the spin axis. The gyro gimbal is supported by the arm of the rotating fork on the gimbal axis. This axis arrangement gives the gyro three degrees of freedom.

MEASURING GROUP.—The measuring group consists of an inner (level) gimbal, an outer (crosslevel) gimbal, training gear, and an umbrella containing two pairs of followup coils, one pair for level and the other for crosslevel (fig. 6-29). With this gimbal arrangement, level is measured in a vertical plane while crosslevel is measured in a plane perpendicular to the deck.

RIGHTING SYSTEM.—The righting system makes the gyro axis assume and maintain a true vertical position. It has two principal parts—the mercury control system and the latitude correction system (fig. 6-28).

The mercury control system consists of two interconnected tanks—one on each side—containing mercury and a gimbal rotation motor that rotates the entire gyro assembly at 18 rpm. While the gyro wheel is horizontal, the mercury level in both tanks is the same. If the wheel tilts from the horizontal, the tanks also tilt, and mercury flows at a controlled rate from the higher tank to the lower. The net effect of the mercury flow and gimbal rotation is that by the time the mercury has reached the lower tank, the tank has rotated 90° from the low point of the gyro wheel, and the pressure exerted here causes the gyro spin axis to precess back to vertical. Thus the gyro automatically erects itself when put into operation, and remains stabilized in a vertical position.

Now consider the latitude correction system. Figure 6-30 depicts the effect of the earth's rotation on a free gyro. A gyro (like gyro A in figure 6-30) located at either pole will be unaffected by the earth's rotation. But a gyro located at the equator will, to an observer standing on the earth, appear to turn backward (westward) with respect to the earth's rotation, at the rate of one revolution every 24 hours. At any point between the pole and the equator, as the figure shows, the gyro wheel will appear to gyrate westward once every 24 hours about an axis parallel to the earth's.

This effect can be compensated for by making the gyro precess slowly eastward at the same rate. The gyro's plane of rotation will then remain horizontal. To do this, a latitude weight at the north point of the gyro wheel makes it precess eastward. The position of the latitude weight is adjustable, so that it can be set for the ship's latitude. A synchro which receives own ship's course, director train and other inputs keeps the latitude weight on the north point as the ship turns and the stable element trains.

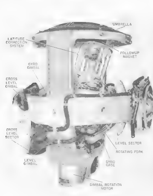
FOLLOWUP SYSTEM.—The followup system performs the actual measurement of level angle and crosslevel angle. The system (figs. 6-28 and 6-29) includes the umbrella and followup coils (mentioned in connection with the measuring group), a followup a-c electromagnet on top of the gyro case, and a level and crosslevel followup (not illustrated). When (because of ship's pitch or roll) the umbrella is not aligned with the gyro, the followup magnet induces unbalanced voltages in the followup coils. The algebraic sum of these voltages goes to an amplifier which uses the amplified signal to control rectifier tubes whose output feeds a d-c servo motor. The motor drives the umbrella until it is aligned with the gyro. Thus the umbrella "follows" the gyro spin axis. The followup units also drive synchro transmitters and operate firing switches for selected level and crosslevel fire.

FIRE CONTROL SYSTEM MK 68

The GFCS Mk 68 is a dual-purpose, fully automatic system used to control 5"/54 and 3"/50 guns. Variations from fully automatic operation—discussed later—are possible, to meet certain tactical situations and emergencies.

The Mk 68 system discussed here is a representative system only; for a detailed discussion of a particular mode of the system (of which there are many), refer to the applicable system OP—OP2649, OP3835, etc.

Basically, GFCS Mk 68 performs the same functions as GFCS Mk 37 except that it is capable of tracking targets traveling at supersonic speeds. The Mk 68 system has numerous dials, handcranks, indicator lights, and similar operating controls, which gives it the appearance of being much more complicated than the Mk 37. Most of these, however, are for checks and test purposes and for placing the system in standby condition. Actually, the system is designed to operate very simply and with fewer personnel than the Mk 37 system. Testing and maintenance have also been simplified through plug-in modules



110.67
Figure 6-29.—Complete stable element gyro assembly.

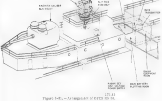
12.150
Figure 6-30.—Effect of earth's rotation on relative position of gyro.

design, built-in testers, and test panels. A typical Mk 68 system layout aboard a DLG is shown in figure 6-31.

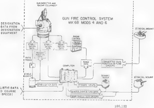
Information Flow and System Components

System components and primary data flow are shown in figure 6-32. The components are discussed separately as to their function in the system. Primary data flow is much the same as in the Mk 37 system.

Before discussing each unit separately, a brief, overall look at the system's data flow may be useful. The director, which serves as the battery control station, furnishes present target position to the computer and stable element. The computer Mk 47 uses this information plus own ship's motion data and ballistic



170.13
Figure 6-31.—Arrangement of GFCS Mk 68.



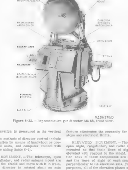
166.122
Figure 6-32.—Gun fire control system Mk 68 data flow.

data to compute gun orders for the 5" guns. The computer Mk 116 (or the gun order converter Mk 20 and star-shell computer Mk 1) is used in conjunction with the Mk 47 computer to produce gun orders for the 3-inch guns and star-shell gun orders. The stable element, which establishes the stabilized horizontal reference plane, provides the director and computer with stabilization signals. Data flow between major units is routed through the fire control switchboard and is continuous as long as the director remains on target—either in radar control or optical control.

Gun Director Mk 68

Gun director Mk 68 determines the present position of the target by either optical means or radar equipment, part of which is located on the director. The optical equipment consists of the director officer's open sight and binoculars mounted on a movable sight bracket, a tracker's telescope, and a stereoscopic rangefinder; the radar equipment at the director (this will vary with different system mods) is the antenna mount and reflector (fig. 6-33). (The radar console is located in the plotting room.)

The normal tracking mode of the director is automatic radar control. The radar provides ranges and angle error signals to the train and elevation power drives. The train power drive rotates the entire director to position the line of sight in train; the elevation power drive rotates the optical equipment and the radar antenna about their elevation axis to position the line of sight. Another power drive (crosslevel power drive) positions the director shield, keeping the elevation axis of the optics and radar antenna aligned with the horizontal reference plane established by the stable element. Thus



3.124(170)D
Figure 6-33.—Representative gun director Mk 68, front view.

director elevation is measured in the vertical plane.

Alternate methods of director control include power operation by means of handwheel or one-man control units, and computer control with regenerative aiding (table 6-1).

TRAIN MOVEMENT.—The telescope, open sight, rangefinder, and radar antenna mount are fastened to the shield and move with it in train. The entire director is rotated about an axis perpendicular to the deck plane to move the director line of sight in train. The electrical connections between the stationary ship structure and the rotating director are made through a slipring assembly in such a manner that train movement is unlimited in either direction. This feature eliminates the necessity for train limit stops and electrical limits.

ELEVATION MOVEMENT.—The telescope, open sight, rangefinder, and radar antenna are mounted so that their lines of sight may be elevated with respect to the shield. The elevation axes of these components are all parallel and the lines of sight of each component are perpendicular to its elevation axis. For practical purposes, all of the elevation planes are parallel. The lines of sight and the radar beam are all moved through the same elevation so that they remain parallel.

The director elevation gearing can move the lines of sight and the radar beam from a depression angle of 25 degrees to an elevation angle

Table 6-1.—Operating modes

Mode	Angle Tracking by	Ranging by	Used for
Auto-track	Auto-radar tracker	Auto-radar tracker	AA, Surface
Console	Handcranks and scopes at radar console	Handcranks and scopes at radar console	AA, Surface
Director Officer's Control	One-man control Mk 4 Mod 4 and optics	Radar (at console) or rangefinder	AA, Surface
Tracker's Control	One-man control Mk 4 Mod 5 and optics	Radar (at console) or rangefinder	AA, Surface
Handwheel	Director officer's and tracker's handwheels and optics	Radar (at console) or rangefinder	Surface
Local control (indirect fire)	Director inoperative, tracking by Computer Mk 47		Surface

170.25

of 95 degrees. Limit stops and electrical limits in the power drive protect the drive mechanisms from damage that would result if these limits were exceeded.

The telescope is constructed so that the instrument body does not move in elevation. Elevation of the telescope line of sight is affected by rotating an objective mirror mounted on bearings inside the telescope body.

The open sight contains a binocular and peep sight at the end of the sight arm. The line of sight is moved in elevation by rotating the open sight about an axis parallel to the telescope elevation axis.

The rangefinder line of sight is moved in elevation by rotating the entire rangefinder about its longitudinal axis. An independent elevation mechanism in the rangefinder drive permits rangefinder elevation to be offset from director elevation when it is necessary to adjust the reticle pattern with the target.

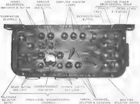
The radar antenna is supported above the shield by a radar antenna mount. The radar beam is moved in elevation by rotating the entire antenna about an axis parallel to the elevation axis of the optical equipment.

A level angle is geometrically added to the elevation of the lines of sight and radar beam to cancel the effect on elevation of roll and pitch of the ship. The level angle is generated by a stable element below decks and is automatically transmitted to the director.

CROSS-LEVEL MOVEMENT.—The director shield is mounted on trunnions so that the entire shield can be rotated in cross-level to keep the elevation plane's lines of sight and the radar beam in a vertical position regardless of the ship's rolling and pitching. The axis of the crosslevel trunnions is parallel to the deck plane.

The director crosslevel gearing can move the shield through an angle of 34 degrees each side of the zero position. Limit stops and electrical limits in the power drive and buffers on the director pedestals protect the crosslevel drive and shield from damage that would result if these limits of movement were exceeded.

Primary control of firing is at Control Panel Mk 110 (fig. 6-34). A two-section, three-position selector switch controls firing and cease firing circuits. When this switch is in the NORMAL position, the gun firing circuit may be completed at one of two positions in the director shield: the director officer's firing key or the tracker's one-man control. When the selector switch is in the CHECK position, both gun firing and cease firing circuits are open. Opening these circuits results in a check fire tone signal being sent to gun positions, which indicates



170.15
Figure 6-34.—Director officer's control panel Mk 110.

that firing is temporarily suspended. When the selector switch is in the CEASE position, the cease firing circuit is completed, sending a tone signal to the gun positions indicating that firing is indefinitely suspended. All firing circuits from director to gun positions are completed through the fire control switchboard.

The director is equipped with two one-man control units (fig. 6-35). Each unit may be used for slewing the director or for one-man tracking in both train and elevation. The one-man control unit is rotated about a vertical axis to control the director train rate and the handgrips are rotated about a horizontal axis to control the elevation rate. The rates generated are proportional to the amount of rotation.

Director Crew and Their Duties

Gun director Mk 68 is operated by a director officer, tracker, and rangefinder operator. The director crew's operating stations are inside the shield (fig. 6-36); they perform all procedures necessary to place the director in operation. Additionally, the director officer is responsible for selecting the operational mode of the director and controlling and supervising the operation of the GFCS Mk 68 and gun batteries controlled by the system.

The director officer, in addition to being in charge of the gun fire control system, maintains sound-powered telephone communication with other stations of the battery plus combat information center and air defense stations. He reports directly to the air defense officer. He notifies the gun stations when firing is to commence and can initiate firing from the director, and he supervises the director crew during all phases of operation.

The tracker assists the director officer, during optical search and target acquisition, in

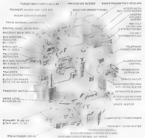


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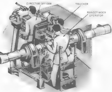
Figure 6-35. —Gun director Mk 68.

controlling director movement in train and elevation. Under certain conditions, he can cancel automatic radar control at his station. The tracker normally initiates gun battery firing with his firing key. He also assists in starting and securing the director.

The rangefinder operator has very little to do in automatic radar control. During surface engagements or gun fire support, he may be required to observe salvo splashes, supply spotting information, and identify targets. During air engagements when the radar is inoperative and shore engagements when the radar is unable to track the target, the rangefinder operator is usually required to furnish ranges to the target. The rangefinder operator also is responsible for energizing the heating and anti-icing, defrosting, and illumination systems.

Director Control and Operating Modes

The director has two basic types of control—handwheel and normal. The type of control is selected by the director officer at his control panel (fig. 6-34). Handwheel control is used



166.123
Figure 6-36.—Director crew stations.

against stationary and slow moving surface targets. The director officer operates the elevation handwheel, and the tracker operates the train handwheel. Normal control is used against all other types of targets and has the following modes of operation:

1. Auto-track. The radar is locked on target and has control of the power drives.

2. Console mode. The radar has control of the power drives but not locked on target; the handwheel and the indicator scopes on the radar console are used to establish and position the line of sight.

3. Director officer control mode. The director officer's one-man control unit and optics are used to establish and position the line of sight.

4. Tracker control mode. Tracker's one-man control unit and telescope are used to establish and position the line of sight.

5. Target designation mode. In this mode the power drives slew to the designated position.

In NORMAL, the train and elevation brakes remain set until the director officer (a) closes his right trigger switch, or (b) presses the target designation button, or (c) presses the CONSOLE button placing the system in the director officer one-man control mode, the target designation mode, or the console mode, respectively. If the radar console footswitches have been cycled to AUTO, transfer from the target designation mode and the console mode to AUTO-RADAR track will be automatic when the director gets on target in range, bearing, and elevation. The director officer can assume control from any other mode by pressing and holding his right trigger switch; he can relinquish control by momentarily pressing his left trigger switch.

The target designation mode is usually employed when an accurate or approximate target designation is available during acquisition. In the designation mode after the director slews to the designated position, search can be made about that position by means of train and elevation handcranks at the console.

The mode-of-operation precedence circuits determine the order in which the operators can assume control of the director. The order of precedence in normal control is (1) director officer's one-man control unit, (2) target designation, (3) radar-auto track, (4) tracker's one-man control, and (5) console. The mode of operation is selected by the director officer and is determined by the tactical situation.

Radar AN/SPG-53

The AN/SPG-53 radar is a part of the Mk 68 fire control system. It affords control of the entire system from the radar console. The radar supplies present range to the computer and angle-error signals to the director train and elevation power drives. In the console mode of operation the two radar operators (range operator and radar trainer), using handcranks and slew controls, keep the line of sight on target by observing the target echo on indicator scopes. The radar console is shown in figure 6-37. The handwheels and slew controls are also used for modifying target designation signals in the target designation mode.

In the automatic tracking mode (normal mode), the director position is controlled by the angle tracking loop. The target-video signal is applied to the angle error detecting system, which determines the tracking error and generates bearing and elevation error signals. These error signals are sent to an amplifier, which supplies power to the director amplidyne.

Computer Mk 47

Computer Mk 47 is housed in two aluminum sections bolted together to form a single cabinet. Each section has a front and a rear compartment. The front compartments house the electromechanical assemblies, and the rear compartments house the electronic units and power supplies. All assemblies are plug-in type. All operating controls, switches, and indicating dials are conveniently located on the front of the computer.

The computer utilizes target present position to compute future target position. Gun and fuze-setting orders based on this information are then computed and transmitted to the gun mounts (fig. 6-32).

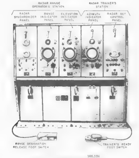
Automatic control is the normal method of computer operation. The computer has three primary modes of operation determined by the type of target — surface, AA-sonic, and AA-supersonic — and the wind track mode used to track weather balloons for gathering ballistic wind data. For surface targets, the computer can also be operated in local control, manual rate control, or optical range submode. In automatic control the computer receives continuous target position data from the director, stabilization data from the stable element, and own-ship course and speed from the ship's compass and speed sensor. It solves the relative motion problem by automatic rate control, and it supplies the director with the generated quantities and stabilization signals necessary to keep the line of sight on target.

The major difference between the modes of operation is a scale factor used to change the operating limits of the rate generating computing loops. The scale factor enters into the relative motion problem by way of the time line and is increased from the surface mode to the AA supersonic mode. Another difference is that in the surface mode of operation the output from the vertical rate of target motion computing loop is not used.

Once the computer has been set up for automatic control, the operator's main function is to monitor it for smooth and correct operation. But during certain types of fire, particularly surface fire, the computer may have to be shifted to local control, manual rate control, or the optical range submode of operation, depending on the tactical problem to be solved. A brief description of each follows.

LOCAL CONTROL.—In local control operation the line of sight DOES NOT originate in the director. The source of data used to establish the LOS in the computer is from outside the gun fire control system. Target position is manually set into the computer by handcranks. Local control is used for indirect fire.

MANUAL RATE CONTROL.—When tracking targets with slow relative rates, it is sometimes advantageous to manually rate control; solution time is reduced, and a smoother solution may be obtained. Because the computer operator has an overall picture of the tactical situation, he is in an ideal position to correct the rate errors without over or under rate controlling. Rate control corrective inputs are introduced by the computer handcranks.



166.124
Figure 6-37.—Radar operating stations.

OPTICAL RANGE OPERATION.—In the optical range submode of operation a continuous, correct, observed present range is not available to the computer. The range servo receiver is de-energized so that the computer's present range will not follow the observed present range signals. The computer's range system becomes a regenerative network, where increments of generated range are used to keep present range up-dated in the computer. When a correct observed range is available, the computer operator uses his handcrank to make present range corrections.

Functionally, the computer can be divided into three main sections—the present position section, the prediction and ballistics section, and the trunnion tilt and parallax corrector section—as shown in the flow block diagram

(fig. 6-38). As shown in this figure, the computer performs the following basic operations:

1. North-south and east-west stabilized coordinates of target present position and target height are established from inputs shown in figure 6-38. These inputs are received from the director, the pitometer log (or other speed sensor), the ship's compass, the stable element, and the wind system.

2. Target position data are compared with corresponding data generated by the computer; differences between compared quantities are utilized as error signals to correct target rate quantities until the correct motion rates are established in the computer.

3. The target motion rates are used to determine target position at the end of time-of-flight.

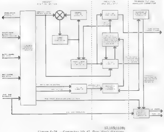
4. The computer determines a line of fire that will hit the predicted target position at the end of time-of-flight.

5. Gun orders are computed (based on the determined line of fire) and transmitted to the gun mounts.

6. Fuze-setting order is determined when mechanical time fuzes are to be used.

A brief description of each functional section, in the order of the fire control problem solution, follows.

PRESENT POSITION SECTION.—The present position section of the computer receives unstabilized, polar coordinate measurements of target present position (range, director train, and director elevation) from the director electrically. The first step by the computer is to convert this



53.105(110B)
Figure 6-38.—Computer Mk 47, flow block diagram.

data, except range, into stabilized quantities. (Range is measured from the system's reference point; therefore it requires no stabilization.)

The next step in the solution of the gun order problem is to convert these stabilized, polar coordinate quantities into rectangular coordinate quantities of target height, east-west horizontal range, and north-south horizontal range. The conversion is performed in two steps; (1) the determination of target height and horizontal range and (2) the determination of east-west and north-south horizontal range.

Target height and horizontal range are computed by a resolver using the equations: target height = range x sine of target elevation and horizontal range = range x cosine of target elevation. The resolver receives a mechanical input of elevation from the elevation servoloop and an electrical input of range from the director.

Target height, one output of the resolver, is used in the rates section and the wind track section. It is also transmitted electrically to the prediction section. The other resolver output, horizontal range, is used in the second step of coordinate conversion.

The north-south and the east-west components of horizontal range are computed by a vector resolver. The inputs to the resolver are an electrical input of horizontal range and a mechanical input of true target bearing. The outputs of the resolver are the required north-south and east-west components of horizontal range. These outputs are transmitted, electrically, directly to the prediction section of the computer and to the Computer Mk 116 (discussed later). These outputs also actuate servoloops that provide mechanical inputs of north-south horizontal range and east-west horizontal range to the rates section.

The present position section also develops stabilization aid signals for transmission to the director, where they are used to compensate for roll and pitch and change of ship's course. They maintain the line of sight on a stationary target as the ship is moving and are increments of changes in own ship's course plus deck tilt correction and rate of change of ship's course plus deck tilt correction.

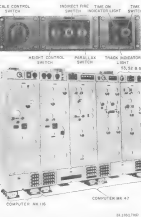
To solve the gun fire control problem, rates of target motion relative to own ship must be determined. This is done by comparing the rates of change of the three stabilized rectangular coordinates—target height, north-south horizontal range, and east-west horizontal range—with corresponding rates generated in the computer. By correcting the generated rates until they agree with the rates of change of the measured coordinates, the correct target motion rates are established for use in prediction. This corrective process, called rate control, is entirely automatic in AA-sonic and AA-supersonic modes of control. A scale factor is introduced into all rate computations. This scale factor, which varies for the different modes of computer operation, is dependent on target speed. The scale factor for AA-sonic is considered to be unity. For AA-supersonic it is 2.5 and for surface it is 1/10. The value introduced is determined by positioning a selector switch on computer panel 53 (fig. 6-39).

Three separate rate loops operate in the present position section of the computer to derive target rate quantities. These loops compute the north-south horizontal range rate, the east-west horizontal range rate, and the rate of vertical linear movement. All three loops operate in the same manner; therefore only one, the rate of vertical linear movement, will be described.

When tracking begins, target height is compared with generated target height. (Actually, only incremental changes in these two quantities are compared.) The system immediately operates to bring these rates into agreement. Once the rates are in agreement, they will remain in agreement until the target's height rate changes. If the target maneuvers, thus changing target height rate, the resulting difference in target height and generated target height causes an error signal proportional to this difference to be transmitted to the corrective target height servoloop. The corrective setting of target height changes generated target height by an amount necessary to make it agree with target height.

PREDICTION AND BALLISTICS SECTION.—Although prediction and ballistics are discussed separately in this section, the computer groups making these solutions are completely dependent upon one another. The prediction group determines target future position based on the time of flight determined in the ballistic computer. At the same time, the ballistic computer uses target future data to determine time of flight. The prediction group and the computer operate simultaneously to make these two solutions. Wind rates and fuze time are also computed in the prediction section.

Prediction.—In order for the prediction group to determine the future position of the target (the position of the target at the end of time of flight) the assumption is made that the target follows a



33.183(170B)
Figure 6-39. —Covers No. 53, No. 52, and No. 51, switches and indicator lights.

straight line course at constant speed during time of flight.

The prediction group performs two distinct steps in the fire control problem solution. First, the future target position is established in rectangular coordinates with respect to the north-south and east-west planes and in the vertical plane. Second, these quantities, together with ballistics corrections, are used to determine the gun's aiming point—the point in space at which the gun must be aimed for the projectile to hit the target. Figure 6-40 illustrates some of the quantities determined by the prediction section.

For the first step, the prediction group receives the target linear movement rates (height, north-south horizontal range, and east-west horizontal range) from which it determines the corresponding linear displacements of the target during projectile time of flight. Three potentiometers operate to determine these displacement quantities. The potentiometers receive the target linear movement rates as mechanical inputs and are energized by time of flight received from the ballistic computer.

Adding the linear displacement quantities (vertical linear movement, north-south linear movement, and east-west linear movement) to the respective rectangular coordinates of target present position (target height, north-south and east-west components of horizontal range) produce rectangular coordinates that define the position of the target at the end of time of flight.

In the second step, the computer's prediction group uses true gun bearing, gun elevation, and aiming position range to determine the gun's aiming point.

Wind System.—Apparent wind rates, necessary for ballistic solution, are computed in the wind system. The wind system receives inputs of own-ship speed and course, wind data, and true gun bearing for computing apparent horizontal wind in and across the plane of fire.

Ballistics.—The ballistic computer uses advance target position coordinates (aiming position range and aiming position elevation) from the prediction group and apparent horizontal wind,

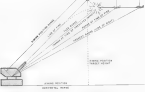


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Figure 6-40.—Computer prediction quantities.

in and across the plane of fire, to calculate the following functional quantities:

1. Time of flight—upon which all prediction computations are based.

2. Superelevation—elevation of the gun above advanced position elevation, necessary to compensate for the curved trajectory of the projectile.

3. Horizontal linear deflection correction—the displacement of the line of fire from the future target position.

The relationship between the ballistic computer and the prediction group is shown in figure 6-41. The computations performed by the ballistic computer are based on data furnished in the ballistic tables. These tables give values of time of flight, drift, and superelevation for projectiles fired under standard ballistic conditions in still air; they also give the effects of deviation from standard conditions.

Fuze Setting Order.—Fuze setting orders are transmitted to the gun mounts by the computer for use when firing projectiles with mechanical time fuzes. Fuze setting order or fuze time corresponds to time of flight and can be computed as a function of fuze range.

The computation of fuze range is based on the assumption that the target continues at a constant course and speed. The prediction solution used to determine fuze range (thus fuze time) is similar to that used to determine aiming range. The inputs for fuze prediction are the same as those for the prediction of aiming range except that dead time is used in computing fuze prediction. Dead time is a hand input that is added to fuze-setting order in the fuze time computer.

TRUNNION TILT AND PARALLAX CORRECTOR SECTION.—This functional section of the computer solves for gun train order, gun elevation order, and parallax.

Aiming position elevation and true gun bearing, obtained in the ballistics and prediction section solution, located the line of fire relative to true north and the horizontal. Consequently, trunnion tilt corrections are required to stabilize the gun orders in the deck plane.

Figure 6-42 is a spherical diagram showing the relationships of the quantities involved in the trunnion tilt and gun order solutions. The steps performed in converting prediction quantities (aiming position elevation, superelevation, and true gun bearing) to gun orders are as follows:

1. Gun elevation, aiming position elevation plus superelevation, is computed in the vertical plane measured from the horizontal.

2. Horizontal sight deflection is computed. This is the angle between the line of sight and the line of fire, measured in the horizontal plane.

3. As part of the conversion from the horizontal plane to the deck plane, functions of level angle and crosslevel are combined with functions of horizontal sight deflection, gun elevation, and director train.

4. Gun train order is established and maintained in the deck plane by some of the quantities obtained in step 3.

5. Gun elevation order is obtained in a similar manner as gun train order.

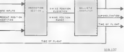

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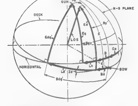
Figure 6-41.—Relationship of prediction group to ballistic computer.



Edg' = Gun elevation order (between deck plane and line of fire).
Bdg' = Gun train order (measured in deck plane).
LOS = Line of sight
B = Relative target bearing
Bd = Stabilized director train
Co = Own ship course
By = True target bearing
Bgy = True gun bearing
E = Target elevation
Ed = Director elevation
Eg = Gun elevation
El = Level angle
Ld = Deck deflection
Lh = Horizontal deflection
V4 = Superelevation
Zd = Crosslevel

178.21

Figure 6-42.—Trunnion tilt solution, spherical diagram.

The computations are performed by a series of resolvers and vector resolvers in the gun order computer step by step.

Parallax corrections are computed for a gun displacement of 100 yards forward of the reference point. By making a standard 100-yard displacement computation, only one computation need be made and transmitted to all gun mounts. At each mount, unit parallax is modified automatically to represent the actual displacement of the mount from the reference point; the individual corrections are then applied to gun orders at the gun mount.

Computer Mk 116

The computer Mk 116 (fig. 6-38) is designed for use with some mods of the Mk 47 computer. The Mk 116 computer discussed here functions in three different modes of operation—NORMAL 3"/50 mode, STAR-SHELL 5"/54 mode, and RAT (rocket-assisted torpedo) mode. In NORMAL 3"/50 mode, it operates in conjunction with the Mk 47 computer to derive gun orders for 3"/50 caliber guns; it transmits these gun orders directly to the 3-inch gun mounts. In STAR-SHELL 5"/54 mode, it operates with the Mk 47 computer in surface mode to derive 5"/54 caliber gun orders and fuze-setting orders for illuminating fire, and it transmits these orders directly to the 5-inch gun mounts. In RAT mode, it supplies relative target bearing, which is used as an aid in the control of anti-submarine rockets.

Except for a few hand inputs (spots and I.V.), the Mk 116 computer receives all inputs from the Mk 47 computer.

The primary function of the Mk 116 computer is to produce gun orders for the 3"/50 caliber battery. The computer contains a prediction and ballistics section for determining target position at the end of time of flight, and a deck tilt section for converting and transmitting gun orders in the proper coordinates.

Converter Mk 20

Converter Mk 20 is used with some Mk 47 computers that are not supplied with Mk 116 computers. The converter, which is installed in the plotting room adjacent to the Mk 47 computer, is used to change 5"/54 caliber gun orders to 3"/50 caliber gun orders. All power and information (other than spots and I.V.) necessary to perform the conversion computations are received from the Mk 47 computer. Therefore, the converter will operate only when the computer is on and transmitting gun orders. Except for setting in spots and I.V., operation of the converter is automatic.

Star-Shell Computer Mk 1

In some systems not supplied with Mk 116 computers, Star-Shell Computer Mk 1 is used to compute star-shell gun orders and fuze-setting orders for 5"/54 caliber gun mounts. It can be operated in two modes—controlled fire or search. In the controlled fire mode, employed when a specific target is to be illuminated, the Mk 47 computer must be operating. In the search mode, the star-shell computer can be operated independently of the Mk 47 computer.

Stable Element Mk 16

The primary function of the Mk 16 stable element and its associated equipment (fig. 6-43) is basically the same as that of the Mk 6 stable element, that is to provide a stabilized reference plane independent of ship's movement. The construction and operation, however, are quite different. The basic principles and problem to be solved are explained in Fire Control Technician G 3 & 2, NavPers 10207 and OP 2209.

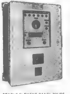
The stable element contains the sensitive element, gimbals, pendulums, pickoff coils, and servo mechanisms that maintain the gyro at a true vertical (fig. 6-44) and generate outputs of level and crosslevel. These outputs are used in the Mk 47 computer deck tilt corrector to compute position angle and true target bearing. Crosslevel is used to keep the director stabilized in crosslevel. Level and crosslevel are sent to the rate transmitter Mk 36 (fig. 6-43), where they are used to develop stabilization signals in elevation for all modes of operation.

Stable element panel Mk 156 (fig. 6-43) contains the controls, indicators, and protective devices required for operating the stable element and rate transmitter.

Dynamic Tester and Error Recorder

The dynamic tester provides a simulated air target for the fire control system. It may be used to check the performance of the entire GFCS Mk 68, or the performance of the director power drives, the computer Mk 47, or the gun order converter.

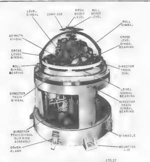
STABLE ELEMENT MK16



STABLE ELEMENT PANEL MK156

RATE TRANSMITTER MK 36

170.26
Figure 6-43.—Stable element Mk 16 and associated equipment.



170.27
Figure 6-44.—Stable element Mk 16, cover removed.

The error recorder uses gun order and fuze order error signals from the dynamic tester to record the amount and direction of error in system or system component performance. This error is recorded on a roll of graph paper.

RELATIVE-RATE FIRE CONTROL SYSTEMS

Relative-rate fire control systems are based on gyroscopic lead-computing sights or computing mechanisms. A number of fire control systems that work on this principle are in use in the Navy at the present time. Most of them are generally associated with 3-inch and smaller guns although some are set up to control larger weapons also. This is in contrast to the Mk 37 and Mk 68 linear-rate systems, which are primarily associated with heavier weapons. The general characteristics and principles of relative-rate gun fire control systems (especially as compared with linear-rate systems) were discussed earlier in this chapter. This section is chiefly devoted

to a somewhat more comprehensive description of one such system—the GFCS Mk 56. However, it is not intended as a fully detailed description of the system.

GUN FIRE CONTROL SYSTEM MK 56

The Mk 56 GFCS (fig. 6–45) is an intermediate-range gun fire control system primarily designed for use against high-speed subsonic targets, but usable also against surface targets. It is most commonly used with 3-inch guns, but can control 5-inch guns also. It is a dual-ballistic system—that is, it can provide elevation, train, and fuze-setting orders simultaneously to two different batteries of different calibers. It can produce a fire control solution within two seconds after tracking begins. The system is capable of either optical or automatic radar tracking in bearing, elevation, and range, and of remote control from the control room below decks. This feature provides for rapid radar acquisition of obscured targets and for blind firing (i.e., firing without visual contact).

The system consists essentially of a two-axis, power-driven, direct-line-of-sight director located above decks, and various computing units located in a control room below decks. Complete radar equipment is included as an integral part of the system. The radar antenna is mounted on the director, and all radar indicators are in the control room (fig. 6–46).

The system is operated by a crew of four men, including the control officer. The latter and the pointer are stationed in the director for optical acquisition and the tracking of visible targets, and the two other men are at a console in the control room. On the console are all radar indicators and operational controls for handling range and positioning the director. Acquisition of obscured targets is accomplished from the console by matching designation dials.

Director line of sight (including radar antenna) is stabilized by a gyro unit in the director. Computation of lead angles is based on director angular rates of motion in stabilized coordinates.

Mk 56 GFCS Fire Control Problem Geometry

The fire control problem is expressed somewhat differently in the Mk 56 GFCS than in the linear-rate systems. Figure 6–46 shows the planes in which the values are expressed and the solution is developed in the director and computer. Two gyros in the director are used during tracking to establish the planes and values used in the solution of the fire control problem. A vertical gyro, similar to the stable element of the Mk 37 system, establishes and maintains the true horizontal and true vertical reference planes. A rate gyro precesses during tracking to develop angular rates proportional to the movement of the director.

The angular velocity of the LOS during tracking can be resolved into angular rates in two mutually perpendicular planes (fig. 6–46). One of these angular rates is elevation rate; the other is traverse rate. The solution, however, requires the use of linear rates of target motion, in a plane perpendicular to the line of sight at target's position. This plane is called the cross-traverse plane and contains linear elevation rate and linear deflection rate. Since the target is not moving entirely in the cross-traverse plane, the range changes at the rate of RANGE RATE measured along the line of sight. Linear elevation rate, linear bearing rate, and range rate are the three basic linear rates of target motion.

Mk 56 GFCS Fire Control Problem Solution

The first step in the solution of the problem is determination of target position. Target bearing and elevation are measured by the director. As the target is tracked, director train and director elevation are measured and transmitted by synchros to the computer. Target range is measured by radar and transmitted automatically to the computer.

Tracking the target is done either optically or by radar. A tracking control unit and a telescope on the director are used for optical tracking. In automatic radar tracking, the tracking signals originate in the radar equipment, and are accurate within one-half mil.

The primary purpose of the vertical gyro is to establish a stable reference plane called the true traverse plane (fig. 6–46). It also measures true elevation of the director line of sight above the horizontal, and cross-traverse angle. Like crosslevel, cross traverse is motion about the line of sight due to movement of the deck, but cross traverse is measured in the cross-traverse plane, which is perpendicular to the line of sight, and therefore differs from crosslevel. The values of true elevation and cross-traverse angles are picked off electrically and are transmitted to the computer, where they

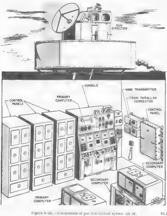


Figure 6-45.—Components of gun fire control system Mk 56. 92.22

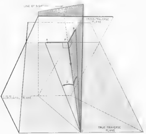


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Figure 6-46.—Geometry of the Mk 56 GFCS statement of the fire control problem.

are used in calculating ballistic corrections and gun orders. Cross traverse also goes to the cross-traverse drive gear of the rate gyro.

The rate gyro controls the drive motors that position the director in train and elevation. It does this by measuring the angular rates of target motion in the forms of electrical tracking signals and by combining these signals with the stabilizing signals of true elevation and cross traverse from the vertical gyro. The algebraic sum of these signals is obtained in a set of pickoff coils that function somewhat like the umbrella and coil arrangement in the Mk 6 stable element discussed earlier in this chapter.

The second step in solving the fire control problem is measuring the rates of target motion.

As described earlier, the target is tracked in elevation and train, and error voltages generated in the pick-off coils go to the computer as rates of target motion (angular elevation rate and angular traverse rate). As for range data, the Mk 56 director has no optical rangefinder; range information is normally supplied by radar, or it can be cranked in manually if necessary. As the radar tracks the target, changes in range (range rate) drive a tachometer generator—a generator whose output voltage is directly and accurately proportional to speed—that produces a range rate voltage signal. From these three rate signals (angular elevation, angular traverse, and range) the computer can calculate lead angles in true traverse and true elevation.

The remainder of the solution process takes place in the computer, which includes the ballistic computer, wind transmitter, parallax corrector, and gun order convertor, with associated amplifiers. Computations are performed by electrical and mechanical networks distributed among these units. Any of these units or all of them together may be considered as the computer.

From present target position and the rates of target motion the computer calculates superelevation and drift. To correct for wind the computer receives by synchro own ship course from the ship gyro compass, and manually introduced values of true wind speed, true wind direction, and own ship speed. Initial velocity and dead time are also cranked in manually. Ballistic corrections are computed in terms of rates. Angular rates (elevation and traverse) from the director are multiplied by range to give linear rates of elevation and deflection. The linear rates are corrected and used to calculate superelevation and other prediction quantities.

The Mk 56 system's geometry is based on the true elevation and true traverse planes as described earlier, but gun orders must be expressed in deck coordinates. The computer therefore converts the computed lead angles to deck coordinates. Additional computer units simultaneously convert these values to produce gun orders for another battery of a different caliber.

Finally, parallax correction must be made. Parallax correction is in principle similar to that already described for linear-rate systems, with standard horizontal correction computed on a 100-yard base and converted at each mount to the proper value. The Mk 56 system also computes vertical parallax correction.

Mk 56 GFCS Summary of System Operation

Figure 6-47 shows the flow of basic quantities in the system when using automatic radar tracking (the usual method of operation). Radar receives target echoes from the antenna and transmits traverse and elevation error signal to the gyro unit as tracking signals, and to the computer as rates of target motion. Signals from the optical tracking control unit in the director may be selected in place of radar. The radar equipment transmits range and range rate to the computer during both radar and optical tracking.

In the gyro unit, tracking signals are combined with stabilizing signals to control the director power drives. As the director tracks the target, director position is measured by synchros, and director train and elevation are transmitted to the computer. The gyro unit also transmits values of true director elevation and cross-traverse angle to the computer.

Own-ship course is introduced to the computer electrically, while own-ship speed, true wind speed and direction, initial velocity, and dead time are introduced manually. The computer calculates lead angles and ballistic corrections. The secondary computers make up and transmit gun elevation order, gun train order, fuze time order, and unit parallax correction. Within two seconds of the start of steady tracking (either optical or radar), the computer is producing accurate gun orders.

OTHER GUN WEAPON SYSTEMS

Thus far we have discussed representative linear-rate and relative-rate gun fire control systems. Although these systems are typical and widely used, they are not the only ones employed in the fleet. In the following paragraphs we shall briefly discuss other systems used in the fleet.

SURFACE FIRE CONTROL SYSTEMS

Surface fire control systems are used to direct the fire of turrets. Most ships having these systems (cruisers and battleships) are in the reserve fleet. These systems are designed to control guns of 6-inch caliber and larger. They are, in general, similar to the Mk 37 linear-rate system. They use rangekeepers instead of computers and stable verticals instead of stable elements; from the

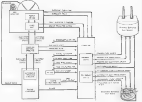

Figure 6-47. — [illegible]

82.116

point of view of the student of this book, these are differences in nomenclature rather than general function.

RELATIVE-RATE SYSTEMS

There are several relative-rate fire control systems used in the Navy. None, however, are used as extensively as the Mk 56 system discussed earlier in the chapter. Some, such as the Mk 63 and Mk 87 are used to a lesser degree than the Mk 56 system, and some (such as Mk 52 and Mk 57) are almost nonexistent. This discussion will be confined to the Mk 63, Mk 86, and Mk 87 systems.

Mk 63 Gun Fire Control System

The Mk 63 system (fig. 6-48) is designed to control 40-mm and 3"/50 guns and is equipped to deal with air targets from 800 to 7,000 yards range, moving with speeds up to 800 knots. The major units in the system are

1. Lead computing sight.
2. Director pedestal (on which the sight is mounted).
3. Radar equipment (with the radar antenna located on a gun mount).
4. Wind transmitter — actually a computer which calculates and introduces wind correction into the system. Its inputs are own-ship course, gun train order, own-ship speed, wind direction, and wind speed.
5. Target acquisition unit (TACU). This unit aids the sight pointer in locating the target when visibility is poor or there are many targets in sight.

The director operator tracks the target manually (the director has no power drive) by training and elevating the lead computing sight on the director and keeping the target image centered in the reticle. The lead angle generated by the sight is transmitted to the gun mount power drive, so that the guns will lead the target. Lead angle is also transmitted to the radar antenna's independent power drive on the gun mount, but here it is applied to cause the antenna axis to lag the gun bore axis by an angle equal to the lead angle. The result of this, of course, is that the radar antenna is always aimed at the target (as is the director line of sight); the axis of the director case (with no parallax input) is parallel to the gun, which points to the future position of the target (fig. 6-48).

Mk 86 Fire Control System

The Mk 86 fire control system is designed to control lightweight 5"/54 guns and other weapons against surface, shore, and air targets. The system is very flexible; it can — with minor changes — be adapted for use with a variety of weapons against all type targets. Some mods function with guided missile systems in the controlling of semiactive homing missiles such as TARTAR.

The Mk 86 system has operating modes to cover just about all possible conditions of readiness. It can operate in (1) Radar Surface Fire, (2) Visual Surface Fire, (3) Indirect Shore Bombardment (with or without a beacon), and (4) Air Action radar, visual, or a combination of both. Three men, a control officer and two gun controllers, operate the system from below decks. On ships with single gun installations, one gun controller's console (and thus one gun controller) is eliminated.

Components of the Mk 86 fire control system are shown in figure 6-49. A detailed description of the Mk 86 system can be found in OP 3645.

Mk 87 Fire Control System

One of the most recent developments in gun fire control is the GFCS Mk 87 (fig. 6-50). It is a dual-purpose, lightweight system designed to control 3"/50 and 40 mm guns. Like the Mk 86 system, it can easily be modified to control larger guns. In its principal operating modes, all system functions are automatic, from the time of target designation to system ready to fire. The components of this system were designed to operate as a balanced and completely integrated weapon control system. The system is self-contained and has three operators — two at the fire control console and one at the optical sight topside.

Of the two manned stations, the fire control console is the heart of the Mk 87 system. It houses the computer (a solid-state digital machine), displays, and control panels. The optical sight, the other manned station, is mounted on a stabilized platform located topside. It comprises various components including gear trains, servomotors, synchros, and a binocular mount for optical tracking and visual observation.

The system can engage two targets simultaneously. It can engage two surface (or shore targets) or one air target and one surface target at the same time.

Additional information on the GFCS Mk 87 can be found in OP 3452.

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Figure 6-48.—Mk 63 GFCS. Principle of fire control problem solution.

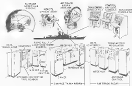

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Figure 6-43. — Gun fire control system Mk 86.

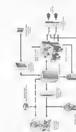

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Figure 8-58.—Gun fire control system Mk 47.

CHAPTER 7

DETECTING AND ASSIGNING AIR TARGETS

INTRODUCTION TO ANTIAIR WARFARE

Antiair warfare includes all measures designed to nullify or reduce the effectiveness of attack by hostile aircraft or guided missiles. The following broad capabilities are necessary to defeat the airborne threat.

1. Ability to eliminate the enemy threat at its base before it is airborne.
2. Ability to defend tactical units by defeating airborne attacks launched against them.

An enemy may attack with aircraft, or with missiles launched from land, from water, or from air. The trend in missiles and aircraft is for higher and higher speeds, and more distant weapon launching capability. Consequently, the time available for surface units to defend against an attack is becoming shorter and shorter. Surface units must be deployed in formations that take advantage of the defense-in-depth concept. This means (1) beginning the effort to counter the enemy attack at as great a distance as practicable from the forces to be defended, and (2) continuing this effort against the attack until it is defeated, or withdraws.

An AAW operation may be divided into three phases occurring successively as the attacking aircraft approach the force being defended.

FIRST PHASE. The first phase includes searching for, detecting, or receiving knowledge of, and evaluating and reporting the enemy attack force.

SECOND PHASE. The second phase encompasses employment of initial active defense measures taken while the attacking aircraft are at a considerable distance from the forces to be defended. Long-range surface-to-air guided missiles (SAMs), and/or combat-air-patrol interceptor aircraft are used in this phase.

THIRD PHASE. The third or final phase is the use of AA guns, short-range guided missiles, and evasive action. During this phase the attacking aircraft are near or within AA gun range of the main body.

Associated with these three phases is a designated AAW area; figure 7-1 is representative. Notice in the figure that three concentric circles divide the total area into a surveillance, a destruction, and a vital area. The actions taken in these areas generally adhere to the explanations of the three phases above, with the surveillance area akin to the first phase, and so on. Figure 7-1 does not describe the areas diametric limits; these change, depending on the nature of the expected attack. Following is a brief description of the areas:

SURVEILLANCE AREA. The surveillance area is an area in which search, detection, evaluation, and tracking are accomplished. Its outer limits are the outer limits of the AAW area.

DESTRUCTION AREA. The destruction area is the area within which destruction or defeat of the enemy airborne threat should occur. It may be subdivided into (1) an air intercept and long-range guided missile; (2) a medium-range guided missile zone; and (3) an AA gun and short-range guided missile zone.

VITAL AREA. The vital area is the area within the destruction area occupied by the forces for which defense is planned. The radius of this area is the enemy EWRR (estimated weapon release range).

Throughout this discussion of AAW, we will consider the force in question to be a fast carrier task group, controlled in AAW matters by one assigned officer. The AAW commander might not be the officer in tactical command of the task group, but he will usually be an officer of flag rank. When formations of more than one task group are involved, the AAW responsibility will most likely be split into sectors and there will be an officer in control of each.

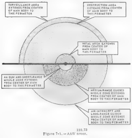

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Figure 7-1.—AAW areas.

AAW UNITS

Ships and aircraft are joined in a task group to accomplish the mission of the group. The mission is dictated by strategic necessity; its accomplishment depends on the proficiency of the group in antiair and antisubmarine warfare, and on the group's offensive striking capability. The number and type of ships and aircraft (hereafter called units) in a task group depend on the operational objectives of the group. Other groups, with similar or different objectives, are joined as needed to fulfill a mission.

As AAW formation is designed to protect an attack carrier, which is the offensive striking unit of a fast-carrier task group. The group is comprised of guided missile and conventional cruisers and destroyers; various fighter, strike, and AEW (aircraft early warning) aircraft; and the carrier itself. Submarines on radar-picket duty may also be part of the AAW formation. (An actual formation showing the locations of the AAW units may not be listed in this unclassified text.) A unit is stationed within a group so that it strengthens the defense capabilities of the group. It must be prepared to direct CAP (combat air patrol) to a target, or to use its own armament. The unit must also engage in passive AAW as regards target detection and evaluation, and transmitting target information to the AAW command ship.

Aircraft are the front line of defense; they have the speed, flexibility, and striking power necessary to engage the enemy at a considerable distance from the friendly force. These fighter aircraft are classified as interceptors, day

fighters, and all-weather fighters. Interceptors are high-speed, short-range aircraft designed to destroy the enemy before he reaches the vital area. Day fighters are designed to engage the enemy aircraft under visual flight conditions. Day fighters also perform interception and area patrol missions. All-weather fighters destroy enemy aircraft under any weather conditions. They are larger and heavier than the other fighters and have greater endurance.

Specially equipped aircraft (AEW) are used to supplement ships and submarines in providing and extending radar coverage of the air defense area, to give early warning of airborne threats, to conduct ECM search, to control fighters, and to serve as radar and communication links between pickets and the main body.

SHIPBOARD AAW WEAPONS

After aircraft, guided missiles and guns are the next lines of defense.

Missiles are classified according to their effective range as follows:

1. Short-range guided missiles have an effective range of 20,000 yards and augment the AA guns in defense of the gun zone.
2. Medium-range guided missiles have an effective range of up to 100,000 yards and engage air targets inside the first line of pickets.
3. Long-range guided missiles have an effective range greater than 100,000 yards.

For further details regarding the use and classification of guided missiles, refer to the next two volumes in this series.

Guns are used against targets that are relatively close to the ship—within 25,000 yards. The most common types of guns used for AAW are 3″/50, 5″/38, and 5″/54 (described earlier).

The 3″/50 RF is a postwar (WWII) product, whereas the 5″/38 was widely used during World War II. The 5″/54, a newer gun, will, in time, replace the 5″/38; primarily because of its faster rate of fire. This does not mean that 5″/38 guns will be removed from ships, but rather that those combatant ships with 5″/38s will gradually be phased out of the fleet. At present, most newly constructed ships do not have 5″/38s, but some converted missile cruisers do.

Auxiliary ships and smaller craft use machineguns in addition to, or in place of, the guns described above. The three types of machine gun mounted on ships are:

1. .50 cal—on small craft.
2. 20 mm—called a light machinegun in the Navy and mounted on small ships.
3. 40 mm—called a heavy machinegun and mounted on small ships and larger auxiliaries.

Machineguns have a high rate of fire, short effective range, and a limited AAW capability. The 40mm has a maximum effective range (MER) of about 4,000 yards, which is greater than that of the other two. The 40s and 20s use impact-detonating projectiles, and a lead computing gunsight to control their fire.

Each type of AA gun has a range (its effective range) at which that gun is most effective. However, it is impossible to set this range precisely. One factor of primary importance is that the effectiveness of gunfire increases as the range decreases. Other factors are considered when establishing maximum ranges for opening fire at air targets. Although gunfire at ranges greater than effective range may result in a few hits, any damage, no matter how insignificant, increases the probability of a kill and has a detrimental effect on the enemy. Opening fire beyond effective range also may effect operation of the equipment and gunnery personnel by the time the target reaches effective range.

Consequently, the maximum effective range of opening fire has been arbitrarily set as the range which will permit approximately 10-second time of flight for the projectile. The approximate MER of opening fire for presently installed AA guns is tabulated in NWP 32.

The probability of kill on targets requiring angles of elevation above 70° is small, because of mechanical limitations of the power drive on AA guns. Therefore, high position-angle crossing targets are extremely difficult to hit. A closing air target at high altitude is also difficult to hit. As a general rule, any enemy air target above 15,000 feet will be assigned to the combat air patrol or to the missile battery for destruction.

THE AAW PLAN

Defense against an air attack demands a high degree of coordination between widely dispersed units in the formation. The attackers can climb to very high altitudes, or they can come in just

over the wave tops. No matter what their altitude, their speed in many cases is supersonic. This means that instantaneous reactions and quickly computed solutions are absolutely essential to the defenders. Even after attaining maximum proficiency, a ship's individual efforts would probably prove futile unless she were deployed in a defense-in-depth formation. Defense in depth requires intensive coordination. Teamwork is then the order of the day and the captain of the team is the AAW commander.

The AAW commander and his staff are usually embarked in a missile cruiser where the entire AAW picture is presented on various display plots. He maintains communications, except during some conditions of electronic silence, with all of the AAW units. He receives all "bogey" (unfriendly air contact) information from the detecting ship or aircraft. Speed of communication and dissemination of target data are essential. Therefore, NTDS (Naval Tactical Data System) was developed to fulfill these requirements.

NTDS General Information

The NTDS is fast and accurate in evaluating and processing naval combat data. It rapidly correlates tactical data from a number of collecting points to provide force commanders with an essentially complete picture of their current tactical environment. NTDS has three basic purposes:

1. Generation of target descriptions.
2. Presentation of the tactical situation.
3. Communication of tactical data.

System components include a variety of electronic equipment, as follows:

Automatic highspeed, general purpose, stored program, solid state, computers.
Displays.
High-speed digital data communication facilities.
Radar video processors.
Readout devices.
Magnetic tape handlers.
Manual data entry devices.
Analog-to-digital converters.

Peripheral to the system are a wide spectrum of sensors and weapons systems. Data derived from radar, IFF (identification friend or foe), sonar, ECM (electronic countermeasure) intercept equipment, and other units of a force, as well as inputs of own ships's course and speed, are entered into the computer for processing. The computer performs data-handling calculations and derives information required for threat evaluation, weapons assignment, dead-reckoning navigation, and communications by way of data links. It also performs the functions of tracking, identification, and height and size determination of an unknown force. All tactical data are presented visually on all display consoles. A representative NTDS diagram is shown in figure 7-2.

NTDS Communications

NTDS provides three separate communication links:

1. The A-link (link 11).
2. The AN/USC-2 link (link 4A).
3. The B-link (link 14).

The A-link is a long-range digital communication link between tactical data units (ships and/or aircraft). Three basic types of information may be received and transmitted via this link—

1. Target tracks.
2. Weapons status and orders.
3. Control messages which regulate the operation of the data link network.

Under normal operation, the data exchanges between NTDS ships proceed automatically and continually on each ship. The unit computer that controls the link equipment is in direct contact, via radio, with unit computers on all other NTDS ships in the force.

The AN/USC-2 data link is used to communicate automatically between the ships and aircraft equipped with this data link. Guidance instructions to interceptors or bombers may be transmitted via this link.

The B-link provides automatic broadcast of tactical data from NTDS-equipped ships to non-NTDS-equipped ships via radio teletype facilities. Generally, one NTDS ship is designated by the officer in tactical command to broadcast NTDS track information to non-NTDS units in the task force. This link may also be used to transmit NTDS data to shore installations.

With the entire tactical situation on visual display before him, and the status of all weapons indicated, the tactical commander is able to best employ his defensive units (aircraft, missiles,

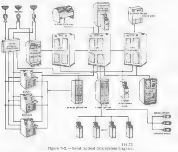

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Figure 7-2. — Naval tactical data system diagram.

or guns). Merely by pressing the required button, he can assign the desired unit instantaneously. Target track and control data are then automatically transmitted to the assigned unit to effectively engage the target. The unit assigned to engage the unfriendly aircraft (bogey) may be a Combat Air Patrol (carrier-based patrol aircraft) or a surface unit.

Weapon Employment

If the bogey does pose a definite threat, the AAW commander decides which weapon in the defense arsenal is to be used. Normally, CAP is vectored to the target if in the target area. The intercepting aircraft may be able to visually identify the target, thereby confirming its belligerent status.

We can miss with CAP just as we can miss with the guns or missiles. CAP may be out of position, the relative speeds may be so great that the attacker might slip by, and conditions of poor visibility or poor radar reception during the terminal phase of the intercept might render CAP useless. Now comes our second line of defense, the surface-to-air missile.

Many things were happening on the missile ship while the CAP intercept was attempted. Extremely accurate fire control radars were being designated (directed) to the target by an

elaborate weapons direction system. The direction system sent continuous target information in three coordinates (range, bearing, and elevation) to the fire control directors in the gun and missile systems. The directors then "locked on" (shifted to automatic radar track) and became electronically independent of the weapon direction system. A computer solution started generating simultaneously with director lock-on in each fire control system. The computers solved the fire control problem and computed the required launcher, missile, and gun orders.

When a ship is ready to engage the target with missiles, it reports this fact to the AAW commander. Upon receipt of more than one such report, the commander decides which ship is to take the target under fire. He considers which ship is in the best position for a kill, and the type and number of missiles remaining on board. If the target is not destroyed after multiple missile salvos have been fired, reliance must be placed upon the last line of defense—conventional gunfire.

Conventional guns are still very much a part of the Navy's armament and they continue to be effective in AAW as indicated by target practice results against high speed jet targets. Gunfire can also disrupt an otherwise orderly mass attack. A gun is not invalidated by a target's speed, but it is seriously limited when the target's RELATIVE MOVEMENT in bearing, elevation, and range exceeds the designed limits of the gun fire control system.

STEPS IN THE SHIP'S DEFENSE PROCESS

The preceding section showed how units are integrated to protect the task group's vital area, but the plan of action for any one unit is necessarily more precise; its broad outline neatly dovetails into the overall AAW plan. In order of occurrence, a ship must detect, display, evaluate, disseminate target information (within the ship), and destroy air targets. If a ship is the first unit in the formation to detect a target, most of its internal steps become steps in the AAW sequence for the task group. Detection, evaluation, dissemination within the task group, and (possibly) destruction of the target become one and the same for the detecting ship and the task group. Other ships will participate in destruction or evaluation if directed or needed, respectively; but they will all use the same internal sequence as outlined above. Note that displaying and disseminating within a ship are always internal steps. Following is a description of the internal steps:

1. DETECTING. Detecting the target is the first and probably the most difficult part of the problem. We have devoted the next section in this chapter to detecting. Air search radars (of various designs) are the primary detecting means, but surface search radars very often detect low flying aircraft. Two other detecting methods are visual, and passive with ECM (electronic countermeasure) equipment.

2. DISPLAYING. Target data are displayed in the CIC (combat information center) of each ship. There are three main display boards, which are called phase 1, phase 2, and phase 3 summary plots. (Smaller ships such as DDs use only two displays.) Phases 1, 2, and 3 stand for long, intermediate, and short range respectively; or, if you prefer, the first, second, and third phases of the AAW problem. Don't confuse these phases with those previously mentioned, because these are relative to a single ship; not to the vital area of the task group. For example, an outer perimeter ship may be in its phase 3, while units in the vital area are in phase 1 or phase 2.

Figure 7-3 shows a phase 1 plot. Each small square has sides which are equal to 60 nautical miles. Since there are 100 small squares, the square mile area covered by the plot is 360,000. GEOREF coordinate identifying letters are inscribed on the edges of the board, and grid lines connect the coordinates vertically and horizontally to "checker" the board. The resulting GEOREF squares make it possible to fix a contact's position in much the same manner as a city is located on a standard road map. You will see later how numbers are used to fix the position within a square.

The main purpose of the phase 1 board is to provide a long range look at the situation. All unidentified air contacts beyond 160 miles from a ship are plotted here. Also plotted is the whereabouts of the formation center. Flagship B in figure 7-3 is the formation center of the four-ship task group shown (ships B, C, S, and T). Notice that certain intelligence items are plotted. Even though the Southeastern United States and the grid lines are drawn approximately to scale, the letters used here are not the actual letters for that locale. Bogey C-8 was detected by ship C at 2015 local time and lost after time 2023—it

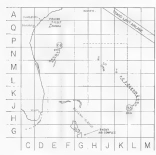

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Figure 7-3. — Phase 1 plot.

was then said to be in a "fade" (depicted by the wavy line). Ship T picked up bogey T-3 and made continuous reports to the formation.

Locate ship S. Notice that it is within a small square that has GEOREF coordinates of JM. (The longitudinal coordinate is always given first.) Ship S is a little northwest of center in the JM square and exactly in the center of a larger square which is shown by the broken lines. The broken-line square represents the area that will be covered by the phase 2 plot on board ship S. The phase 1 plot is also the one on board ship S. Now shift to figure 7-4, the phase 2 plot.

Ship S is in the center of the plotting board and northwest of center in the JM square. Bogey T-3 is making an attack from the southeast and his position in the KL square is the same as that which he occupied in the phase 1 plot. The physical dimensions of the squares on the phase 2 plot have been enlarged but the geographical area they represent remains the same. Now there is a quick and convenient way of relating bogey T-3 to ship S. He bears 135° true at about 90 miles.

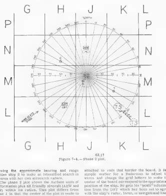

Figure 7-4. — Phase 2 plot.

Knowing the approximate bearing and range enables ship S to make an intensified search in the area with her own airsearch radars.

The phase 2 plot shows the surface units of the formation plus all friendly aircraft (AEW and CAP) within its radius. This plot differs from phase 1 in that the center of the plot is made to represent the geographical position of the ship (ship S in this case). The grid coordinates are adjusted periodically as the ship moves over the ground. Unlike the grid lines that are inscribed on the phase 1 board, these are wires which are attached to rods that border the board. It is a simple matter for a Radarman to adjust the wires and change the grid letters to make the center of the board correspond to the approximate position of the ship. He gets his "posit" information from the DRT which has been set to agree with the ship's radar, loran, or navigational fixes.

The phase 3 plot is an enlargement of the close-in area of the phase 2 plot. Unidentified air contacts within a 50-mile radius are displayed here. The phase 3 plot is important in ships

that do not have a long range target acquisition capability.

Figure 7-5 shows how to fix a target's position within a GEOREF square. The square is divided into equal increments in both latitude and longitude. Bogey 7-3 would be reported as KL 23. The numbers shown in the figure are not inscribed on the plotting board or on the grid wires. It is useless to scribe wires that can move with respect to one another. The Radarman who is reporting the bogey's position merely estimated the divisions of the square. Other numbering systems which have about five increments are used, but the principle remains the same.

Finally, GEOREF points are not "right on the nose." Inaccuracies stem from reporting delays and from grid wires that have been incorrectly set. Moreover, the actual position within a square is an estimate by the person reporting the contact. Since NTDS was developed, however, reporting delays have been greatly reduced, and the actual target position within a square is more accurate.

3. EVALUATING. The process of evaluating is continuous from the moment of detection to the subsequent intercept of the target. The tools used most often are the target's relative

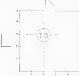

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Figure 7-5.—Locating a Bogey within a square.

position, his course, speed, and altitude, and his response to an IFF (identification friend or foe) challenge.

As we have seen, a contact may first appear on our display as a GEOREF report from another AAW unit. Included in this report will be a calculation of the contact's course, speed, and altitude. This information is sometimes hastily computed because of the need for immediate dissemination to the other units in the task group. Initial minor inaccuracies will be noted quite often when compared to the subsequent reports from that same reporting unit.

The mere mention of a contact on the reporting net indicates that the reporting unit is unable to receive the correct IFF response. It is quite possible that the IFF equipment may be functioning improperly. The only reasonable recourse in the event of no IFF return would be to get as many AAW units as possible on the contact. Perhaps they can receive the correct IFF response or locate the contact on their ECM gear. If the IFF equipment fails to identify, maybe the contact can be recognized by evaluating ECM radar characteristics. You might also identify the bogey by accounting for all of the known friendlies in the area. This process of elimination and the evaluation of ECM information consume time, and time is not always available. If time is short and we can't receive the correct IFF response, we must assume that the contact is an enemy.

Most of the defensive decisions for the group will be made by the AAW commander, but each ship is set up to evaluate independently, and to make its own decisions if necessary. The factors and questions which follow are considered simultaneously by the AAW commander and each ship's CIC evaluator.

The evaluator is responsible for identifying the contact, and for determining the type of attack he is most likely to make. He is also responsible for an estimation of the target's weapon release range. Generally speaking, the determination of the target's weapon release range is not of paramount importance when intercepting with aircraft, since the practice is to get out there with CAP as soon as possible. It would be a definite factor however, in the case of a saturated raid when the evaluator must select the most critical target. The most critical target, excluding the type of weapon he carries, is usually the target with the nearest or quickest CPA (closest point of approach), or a target involved in jamming.

The target's radar characteristics, along with his speed and altitude, may reveal his aircraft type and, therefore, his weapon capability. Armed with this information, the evaluator, who is well versed in aircraft tactics, can make an educated guess as to which is the most critical target in regard to weapon type and release point.

Along with the selection of the most critical target comes the necessity to know the ship's defensive capability. The evaluator must be knowledgeable in this area in order to recommend the type of armament to be used in the kill, and to be reasonably sure that the selected weapon is capable of a kill. What are the weapon limitations? How high and how far can the missiles go? Is the missile control equipment locked on and ready? Will the target enter the missile blind zone (firing cutout area caused by ship's structure)? If so, will the ship have sufficient time to change course and unmask her missile battery? Or, would it be better to fire a nuclear missile in the face of a concentrated raid? Are these nuclear missiles available? For that matter, what is the actual count of all missiles remaining on board?

Further, are all of the missile directors engaged? Can AA gunfire cope with a particular target? Once again, how high is he, what is his relative movement, is he in the blind zone, or will he reach his weapon release point beyond the range of AA gunfire? In the latter case, perhaps a shifting of targets at one of the missile directors is indicated. These are only some of the many questions confronting the CIC evaluator.

All intelligence information is collected and made available to the evaluator. A knowledge of enemy aircraft capabilities and limitations, both in equipment and tactical application, is essential. The evaluator must be able to estimate the target's priorities and probable intentions. He must be aware of the geographical location of friendly forces, particularly in relation to enemy air facilities. In addition, he must keep abreast of any weather or atmospheric developments and their effect on flight operations and radar performance.

Evaluation is a process which involves a continuing appraisal, or estimate of the existing air threat. It terminates with the "splashing of the target." With very little time available to detect and successfully counter a raid, it is mandatory that responsibilities be decentralized as much as possible. There may be no time for the commanding officer to request permission from the AntiAir Warfare Commander to launch short range missiles, and there may be no time for the evaluator to ask the commanding officer for permission to take the raid with CAP. And sometimes, when confronted with a surprise attack, there is no time for the weapons officer to wait for information from CIC. As a matter of fact, the director officer may commence firing if the situation warrants.

4. DISSEMINATING. Transmitting information to the other units in the group, and keeping stations on a ship informed, is disseminating externally and internally, respectively. External dissemination to other AAW units, and the AAW commander, is the responsibility of CIC personnel. Internal dissemination is of more concern to the readers of this text.

All ships use sound-powered telephones to complete the communications link between CIC and weapons' battle stations. Newer ships, specifically those armed with missiles, often have closed-circuit television equipment on board. A television camera is focused on the phase 2 plot in CIC and receivers are located in various control stations throughout the ship. Examples of receiving stations are:

a. Weapons Control Station
b. Commanding Officer's Tactical Plot
c. Flag Plot
d. Air Control Section of CIC

Television equipment has done much to eliminate the excessive time consumed when transferring bogey data exclusively by sound-powered telephones. But telephones are still used for action commands and to provide an audio backup for visual information. They continue to be the sole information link to stations that do not have a critical evaluation or a weapons control assignment.

The most important information disseminator for weapons personnel is the weapons liaison officer (WLO). This officer is stationed in CIC at a location which commands a good view of the phase plots and facilitates direct conversation with the evaluator. The WLO is on the weapons battle control telephone circuit, which also includes all officers who are assigned to weapon control stations. It is his responsibility to keep all stations on the circuit fully informed in all matters pertaining to the battle. He forwards information such as "warning red, yellow, or white" which means that an attack is imminent, probable, or improbable. Warning conditions

are prescribed further by "weapons tight" or "weapons free." Weapons tight means that shipboard weapons will not be fired (unless enemy aircraft are committing hostile acts) because friendly forces (usually CAP) are in the firing area. Weapons free means that there are no weapon delivery restrictions, and may be used as the authorization for a ship to "fire when ready." The latter usage depends on the standard operating procedure for the task group. The WLO performs other, more mechanical, actions in getting directors on targets; these will be discussed later in this chapter.

5. DESTROYING. There is very little we can say here about destroying targets. Once a gun projectile is launched it follows a ballistic flight plan which cannot be controlled by the launching ship. Effective gunfire depends on solving the fire control problem, aiming the guns correctly, and maintaining a continuous ammunition supply. The destruction of targets by missiles will be discussed in the next two volumes of this series.

TARGET DETECTION

It is possible to detect a target by using passive equipment such as electronic countermeasure (ECM) gear. This supersensitive equipment detects electromagnetic radiation, indicates its direction, and measures the transmitter's frequency, pulse width, and pulse repetition rate (PRR). We can even determine the antenna's rotation rate with this gear.

The ECM operator refers to a publication which described the operating characteristics of known radiating equipment. He then ascertains, what type of equipment he has detected and, more important, what type of vehicle the equipment is probably mounted on. In other words, he makes an educated guess as to whether the contact is a particular type of enemy aircraft, submarine, or perhaps a member of his own operating force. ECM gear has serious drawbacks in that it cannot measure the range or altitude of the contact, even though range might possibly be determined by ECM triangulation.

Air search radar is the primary means by which we detect targets. The air search radar fixes the target's position in two coordinates—range and bearing. Some CIC air search radars, particularly those associated directly with fire control equipment, have a height- or altitude-finding capability. The three coordinate radars have a distinct advangate when designating a fire control director to the target. The height quantity is converted into an angle of elevation and eliminates large sector searching in elevation by the director. In order to make use of height, we must have a weapon direction system which can designate in three coordinates. The result is a decrease in the target acquisition time required by the fire control director, provided the search radar has been correctly aligned with the FC radar. Since radar is such an integral part of modern weaponry let's discuss it in more detail.

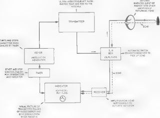
ELEMENTARY RADAR THEORY

As you remember from an earlier chapter, radar essentially is a method for determining, by radio echoes, the presence of objects, their range, bearing, and elevation, for recognizing certain of their characteristics, and for making use of this information. A complete radar installation is itself referred to as a radar; the term is used to denote the equipment as well as the technique.

The bare elements of a radar system's operation are shown in figure 7-6. A high-powered transmitter sends out a short pulse of intense high-frequency radiation from a special antenna so that it issues more or less as a beam. Then the antenna is switched by a duplexer to a sensitive receiver, which picks up radio echoes reflected by targets in the path of the beam. The echo (pip or blip) shows up as a bright spot or a kinked line on the screen of a cathode-ray tube. (The tube is like that of a television receiver, but doesn't present a picture—only blips or pips.) The functioning of the system is coordinated by a timer, which transmits pulses to the receiver and keyer. The keyer in turn starts and stops the transmitter.

With electromagnetic radiation traveling at the speed of light (186,000 miles per second), it's obvious that all of this happens quite fast. In 1/1,000,000 second (1 microsecond) radio energy travels 328 yards. Since the pulse of radio energy has to travel to the target and return, a time indication of 6.1 microseconds represent 1,000 yards range, although the pulse has traveled 2,000 yards going to and from the target.

Now that we have a general idea of the functioning of a basic radar, let us discuss (briefly) search radar.



53.106
Figure 7-6.—Elements of a Radar System (block diagram).

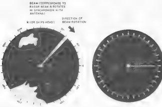
SEARCH RADAR AND IFF

Aboard ship, radar equipment has two general applications—for search and for fire control. Search radar displays are centered in CIC. Although we are primarily concerned with fire control radar, you must in order to understand the target detection and acquisition process know something about search radar. The three types most commonly used in surface ships are air search, height-finding search, and surface search. A representative search radar presentation is shown in figure 7-7; this is the commonly-used PPI (planned position indicator) display.

An air search radar's primary function is warning of the presence of aircraft at extreme ranges. It is called a two-coordinate radar since it measures only range and bearing.

Height-finding radars are three-coordinate radars. They are capable of discriminating between targets that are close together, and they are capable of measuring range, bearing, and altitude. The altitude quantity is converted in the weapon direction system to an angle of elevation by the fire control directors, thereby decreasing their target acquisition time.

Surface search radars measure the range and bearing of surface contacts to assist in navigating the ship, or to send surface target information to the weapon direction system. They are also effective in detecting low flying aircraft, since their radar energy is concentrated at low angles of elevation.



A B

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Figure 7-7. — PPI Scope presentation.

As we stated earlier, on a radarscope presentation a target is a blip, not a picture. It's either a shapeless blurred spot or patch, or a jagged distortion in a line. Around the blip is "grass" — the visual equivalent of audible noise in a radio transmission. (It's called "grass" because in an A-scope presentation electronic noise in the line traced by the electron beam in the cathode-ray tube does appear as wavering, moving filaments reminiscent of blades of grass.) In search radar units, any target smaller than a geographical feature has no discernible shape. This is especially true of aircraft targets. When aircraft come within search radar range, there's nothing in the blips to indicate whether they're friendly or enemy.

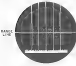
To deal with this problem we have IFF. IFF equipment aboard ship functions in conjunction with a search radar, but the IFF system includes also equipment aboard the aircraft. The radar beam from the interrogating ship "triggers" automatically the IFF equipment on the friendly target. The latter then transmits a coded signal which shows up on the indicator scope of the regular radar set on the interrogating ship. The interrogating ship and the target must carry matching IFF equipment. For security, we use coded signals.

FIRE CONTROL RADAR

Fire control radars must be able to determine range, bearing, and elevation of a target with a high precision to achieve destructive gunfire. They must also have good target resolution; i.e., they must be able to distinguish between blips which are very close together. This is necessary to permit accurate pointing, training, and spotting.

Surface fire control radars (e.g., Mk 13) are used in conjunction with surface batteries on cruisers. This radar must measure range and bearing accurately to provide data for the solution of the surface fire control problem. Figure 7-8 shows a B-scope of the type used in surface fire control radar. The transmitted pulse and the start of the time-base sweep are on the bottom horizontal line. The sweep is made to move from bottom (minimum range) to top (maximum range) on the scope face. The range line is an electronic measuring indication which is made to move up and down the scope face in response to mechanical gearing and electronic circuitry controlled by the radar operator. To measure range, the operator rotates a handwheel until the range line just touches the bottom edge of the target echo and then reads a range counter; we are slightly under ranged in the figure.

Notice the five vertical lines in the figure; these are not sweep traces. The intensity of the sweep traces has been decreased by the operator so that he can better see the target pip. If the intensity were increased to maximum, the scope face would be illuminated within the limits of the horizontal transmitted pulse line. This tells you that there exists a vertical range sweep for each minute horizontal segment of the transmitted pulse line. The actual number of range sweeps is determined by the pulse repetition frequency of the radar and the antenna scanning frequency which will be covered in a moment. In figure 7-6 we learned that a timer fires the transmitter and starts the range sweep simultaneously. The pulse repetition frequency of a radar is the operating frequency of the timer measured in cycles of operation per second.



53,109.2
Figure 7-8.—B-scope.

Now let's measure bearing. The center vertical line is called the bearing line; it always represents the exact trained position of the director. Or you could say that it is aligned with the vertical crosshairs in the director's optical telescopes. If optical tracking is impossible the director can get on target by training right (in the illustration) until the bearing line exactly bisects the target pip. The target would appear to move to the left on the scope as the trainer moves the director and its antenna on target. If optical tracking were used, the bearing reference would be the vertical crosshair in the director trainer's telescope, but the radar picture would be the same as if radar tracking were used.

The bearing relationship between the target echo and the director's line of sight (or the bearing line) is obtained by causing the radar antenna to scan horizontally. Scanning in surface radars means oscillating the antenna back and forth rapidly through a small angle; the center of which is the bearing line of sight of the director. When the director is exactly on target, the target is illuminated on the scope when the antenna is at the middle of its scanning arc, thus causing the bearing line to bisect the target echo. In figure 7-8 the target was illuminated when the radar beam was positioned to the right of the line of sight. To present this relationship electronically, the vertical range sweeps (without which no pip indication is possible) are made to scan left and right on the scope. When the antenna is at its farthest rightward position, the range sweep will be farthest to the right on the scope. When the antenna scans back to the middle of its arc, the range sweep occurs coincident with the bearing line, and so on. The sweep is made to scan left and right by applying an a-c signal to the scope's horizontal deflection plates; the same a-c signal which drives the antenna back and forth. The other vertical lines in the figure are spotting reference lines for deflection spots.

Antiaircraft fire control radar is more complicated than surface fire control radar. This is due primarily to (1) greater target velocities, (2) target elevation measurement, and (3) a need for automatic radar tracking. The automatic tracking feature is not found in all AA systems,

but it is included in all missile systems and in the newer gunfire systems. In this discussion we'll concentrate on the automatic tracking Mk 35—the radar used with the Mk 56 GFCS.

The Mk 56 system has four displays—a double display for range (the A/R-scope), a display for bearing (the B-scope), and a display for elevation (the E-scope).

The A/R-scope displays two traces—the A trace and the R trace. The A trace extends from zero to 30,000 yards. The significant features of the trace as illustrated in figure 7-9 are:

1. Outgoing transmitter pulse blip. This is an up-down jog of the trace at the zero range point.

2. Range notch. This is a depressed portion of the trace. By cranking a control on the radar console the operator can shift the notch in range so that target blips may fall within it, as illustrated in the figure. When the notch is adjusted so that a target blip is in contact with the left-hand side, the target is said to be gated.

3. Target blips. These are up-down jogs of the trace, each corresponding to one target.

The R trace is an expansion of a portion of the A trace. Only the left side of the range notch shows on the R trace; this is the range step. The R trace is 1000 yards long; there is a small gap in the trace to represent the location of the nearest even 1000-yard point in range. As the radar operator cranks the range notch uprange or downrange, it moves correspondingly on the A trace, but on the R trace the range step remains fixed in the center of the trace while the blips and range markers move past it. In addition, the blips move leftward or rightward on both traces to correspond to their movements downrange (decreasing range) or uprange.

The diagram above the illustrated A/R traces in figure 7-9 shows the spatial relationship of radar and targets which the traces indicate.

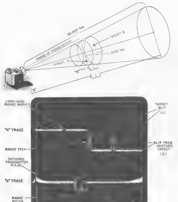
The E-scope (fig. 7-10) shows range (horizontally) from 0 to 30,000 yards, and director true elevation (vertically) in degrees from −10° to 90°. The vertical width of the trace depends on the type of antenna scan. There are two types of scan—spiral for searching and conical after the radar has locked onto target. As the radar beam goes through a complete spiral scan cycle, the trace covers a 12-degree band, the center of which is at the angle corresponding to the true elevation of the director. In conical scan, the trace covers a 3-degree band. The range strobe line (range mark) appears as a bright vertical line extending from top to bottom of the sweep. Target echoes appear as short vertical lines. Two curved lines on the scope face furnish an indication of target altitude in feet. A target on the lower curved line is at 10,000 feet altitude; target on the upper line is at 30,000 feet altitude. Other target altitudes can be estimated.

The B-scope presentation (fig. 7-11) shows bearing (horizontally) 6° either side of director train, and range (vertically) 1000 yards either side of the range mark. The trace appears as a vertical band, with its center always at the center of the scope. The trace width in bearing depends on antenna scan; 3° for conical scan, and 12° for spiral scan. The range mark appears as a horizontal line at the center of the scope, extending across the entire width of the trace. Target blips appear as horizontal lines.

When searching for a target, the radar tracker watches the E-scope. Since spiral scan is used for searching, the target blip will be visible on the E-scope when the director line of sight is within 6° of target bearing and 6° of target elevation. In addition, for the blip to be visible on the B-scope, the range mark must be within 1000 yards of the target blip. As soon as the target blip appears on the E-scope, the radar operator slews the range mark to bring the blip within the B-scope. When the radar tracker sees the target in the B-scope, he turns the range crank to bring the blip up or down to the range line, and simultaneously turns the bearing crank to bring the blip right or left to the director bearing line.

Figure 7-12 shows the appearance of all three radar scopes for different positions of the target. The equipment is on target C; therefore the blip from target C is against the range notch on the A sweep, at the step on the R sweep, at the center of the trace in the E-scope, and at the center of the B-scope. All targets covered by the 12-degree spiral scan appear on the A sweep and E-scope. Target E does not appear on any scope because it is more than 6° from the antenna axis. Target A does not appear on the B-scope because it is more than 1000 yards from the range mark. Targets A and D do not appear on the R sweep because they are more than 500 yards away from the range step.

When the target selected is gated in the A/R scope, and is (as target C is) on the intersection of the zero lines in the B-scope, the radar operator can by operating a foot switch cause the system to track the target automatically.



92.31
Figure 7-9. — A/R-scope presentation.

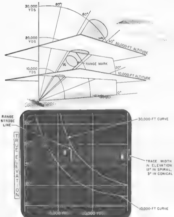


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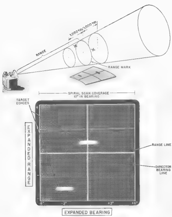
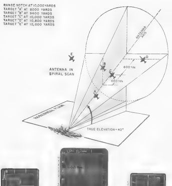
Figure 7-10. — E-scope presentation.



92.34
Figure 7-11.—B-scope presentation.



93.35
Figure 7-12. — Interpretation of radar traces.

DIFFICULTIES IN DETECTING

Atmospheric conditions will sometimes affect target detection. A moisture-laden cloud might appear to be an air contact on the scope. This false target would soon be discounted by the radar operator since it will have a very low speed. Rain squalls, storms, etc., may temporarily obscure actual air contacts. But if we are hampered by weather, the attackers are also. Extreme adverse weather conditions lend some doubt as to the feasibility of an air attack.

Target detection is made more difficult when the enemy is "jamming" our radar. One form of jamming is more or less semiactive and consists of dropping "rope" or "chaff" from an aircraft. This jamming material is made of aluminum foil strips which are cut to resonate at a particular frequency. The effect is similar to what we would see if numerous transmitters were reradiating our air search energy back to us. This type of jamming is easily recognized on the scope because of the almost linear pattern it presents. Its success lies in the aircraft's ability to saturate our scope with false targets, thereby obscuring the real ones.

Some electronic countermeasure equipments can be used for active jamming. We are more concerned with enemy aircraft acting in this capacity than surface units because of the latter's range restrictions at radar frequencies. ECM equipments can automatically find your transmitting frequency and pulse repetition rate, and thus transmit "down your throat." On A-type radarscopes this type of interference shows up as "railings" or "fence posts." On B-type scopes it may look like sine waves or "snow."

To be effective, the chaff aircraft must penetrate our entire AAW network. It is doubtful that he can do this since the chaff pinpoints his position to practically every fire control director in the task group. Also, he would be recognized immediately as an enemy, thus eliminating the normal evaluation time. If he chose to drop chaff outside of our defenses, he would be announcing an attack. Moreover, fire control radars have been known to look right through this chaff. Some methods of combating chaff and other jamming are discussed in the next section (countermeasures).

The most pronounced single limiting factor in air searching is the radar's inability to follow the curvature of the earth and detect low altitude targets beyond the horizon. Some radio frequencies (shortwave) will follow the curvature of the earth for great distances provided the waves are propelled by sufficient power. This is accomplished by bouncing the radio wave between the earth's surface and the ionosphere. Since the ionosphere curves around the earth, the reflected radio waves will curve also.

Shortwaves are in the high frequency range of the spectrum; radar waves are considerably higher in frequency. The higher radar frequencies will penetrate the ionosphere with little or no reflection occurring. They penetrate primarily because of their shorter wavelength. We will not get involved in a discussion concerning the "whys" of this penetration. We are more interested in the end result, which is a desirable straight line of sight transmission.

You may have decided at this point that a low frequency radar, making use of the ionoshpere reflection phenomenon, could provide adequate coverage of the blind area beyond the horizon. Perhaps it could. The technical problems encountered in this attempt however, would be staggering. We would have to know the height at which reflection of the wave occurs, and the primary factor in this determination is the ionoshperic density. Density of ionization at different altitudes makes the ionoshpere appear to have layers. Actually there is no sharp dividing line between the layers of ionization. Suppose we could predict how much density is required to reflect the wave, could we then predict with accuracy at what height reflection would occur? Even with an educated guess, we would be further victimized by sporadic ionizations which occur at varying density in each layer.

If we were to suspend ourselves in the ionosphere and look down to the earth's surface with magnified vision, we might be able to see an aircraft standing out in bas-relief against the water. Electronically speaking this is not the case. It would be difficult indeed to detect a target, say, 50 feet above such a massive reflecting surface.

If we did not have a line of sight transmission in radar, the time factor would be in error. Errors in time mean errors in range. Errors in elevation and bearing would also be noted. To sum it up, current knowledge and the need for accuracy forces us to use higher frequencies, thereby making the blind area something with which we'll just have to live.

A straight line extending from the air and surface search antennas and tangent to the horizon, represents the maximum detectable range of zero altitude targets. This range is proportionally increased by an increase in the target's

altitude. Detection range could also be extended by raising our antennas' heights. Unfortunately we cannot depend on the targets accommodating us by flying at high altitudes, nor can we raise the heights of the transmitting antennas beyond the restrictions imposed by the ship's designers. We must make another tack.

Instead of considering the AAW unit and its "low flyer" detecting limitations, let's look at the unit as an integral part of a whole. The whole in this case is a task group. Tactically speaking, it is our mission to protect the vital area of the task group and not the units comprising it. Protecting the vital area is easier than protecting a single ship when we discuss the problem in terms of target detection.

The task group is deployed so that some of the units are operating many miles from task group center. These outer perimeter units extend greatly the task group's radar surveillance. They can be used to destroy a target with their ship's armament or to vector CAP. Still other units with the same capability are strategically placed between the outer perimeter and the task group center.

AEW aircraft are stationed above the task group as insurance against the penetration of the surface units' radar network. This aircraft represents a great increase in radar antenna height; consequently, its radar range capability is limited only by altitude and the design characteristics of its radar. The AEW is a flying station; and by utilizing the NTDS, rapidly and accurately it can be used to vector the combat air patrol plane.

Let us next discuss some countermeasures against jamming.

DETECTION COUNTERMEASURES

Many antijam circuits have been incorporated in our modern radars to combat active jamming. Frequency control power devices change transmitting frequencies at the touch of a switch on some radars. Electronic differentiating circuits change the "fence posts" into narrow spikes before they are displayed on the scope. Manually operated pulse repetition controls vary the repetition rate of our radars. Some radars have an automatic pulse repetition variance that operates at a random rate, making it virtually impossible for countermeasure gear to lock on. The fence posts would then wander across the scope but the target's movement would be consistent in direction and therefore easily discernible from the wandering fence posts. Circuits such as fast-time constant (FTC), instantaneous automatic gun control (IAGC), and sensitivity time control can all be used to reduce abnormal signals while processing normal signals without appreciable loss. A relatively new development in electronic counter-countermeasures for gun fire control radars is the radar signal processing equipment (RSPE), which is explained in the following paragraphs.

RADAR SIGNAL PROCESSING EQUIPMENT

As stated above, RSPE is a relatively new development in the field of electronic counter-countermeasures (ECCM). It is added to existing gun fire control radars used for the automatic control of antiaircraft guns. RSPE consists of a cabinet containing its circuitry (fig. 7-13), a range operator's control unit (fig. 7-14), and a trainer's control unit (identical to the range operator's control unit). RSPE can be disconnected from the fire control radar with a single pushbutton.

The main purposes of RSPE are to give faster, more accurate target acquisition and provide continuous target track through high level interference. Each received echo of a transmitted pulse is digitally processed, and the results are stored in a memory to provide the radar with the following:

1. Complete automatic target acquisition within the spiral scan of the radar beam.
2. Virtually instantaneous range tracking of targets.
3. Automatic passive track against almost all forms of noise and jamming.
4. Logarithmically processed video and suppression of most forms of jamming signals for improved scope display.
5. Automatic transmitter frequency slew when active jamming is sensed.

The automatic acquisition capability, which is a necessary function of rapid reaction to various jamming environments, also enables faster fire control action in a clear environment. Using automatic acquisition, the radar will acquire the nearest target within the spiral scan beam (e.g. target A in figure 7-12); lock on in range, bearing, and elevation; and shift to conical scan, all within about one second. If, after about 3 seconds of tracking, the target is determined to be opening or closing at a speed less than 100

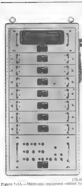


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Figure 7-13. — Electronic equipment cabinet for RSPE Mk 1.

knots, the RSPE will reject it, return to the acquisition mode, and search for the next closest target (e.g. target B in figure 7-12). The operator may override the RSPE and continue to track a stationary or slow-moving target if desired.

This brief look at the RSPE is intended only to give you an overall picture of what the equipment does. Additional information on its description and operation can be found in Fire Control Technician G 1/C, NavPers 10208.

DIRECTOR ASSIGNMENT WITH A TDS

Perhaps the term "target designation" evolved from the designation, or target numbering process in CIC. Or, perhaps designation is related to assigning ships to formation stations; such assignments are often prefixed by "desig." But in weaponry, designation means assigning or directing a fire control system to a specific target. A target designation system (TDS) or a weapon direction system (WDS) does this job. A TDS directs gun fire control systems and will be discussed in this section. A WDS directs gun fire and missile fire control systems, and it will be covered in the next section of this chapter.

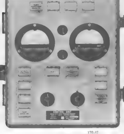
The Naval tactical data system is used to supply information to the TDS and WDS by a communications link (fig. 7-15), as explained earlier in this chapter.

Toward the close of World War II, the usual method of designating a target was by sound-powered telephone. Usually the designation originated with CIC, which plotted target range, bearing, and approximate elevation from information provided by search radar. The WLO (then the GLO) stationed in CIC would call the selected director and give it the target coordinates. The director would then slew in manual control to the coordinates specified, search in that vicinity, and begin tracking the target when it was located. Once a director tracks a target (then and now) the designation process is complete. Fire control system mechanisms and personnel then control all matters prior to target destruction.

Earlier in the chapter, we did not list target designation as a separate step in the ship's defense process because it broadly falls within the "disseminating" category. The same is true for "target acquisition," which is the term used to describe the actions of directors in acquiring targets. Because of their interrelation the actions for designation and acquisition will be covered together in the following sections.

FUNCTION OF A TARGET DESIGNATION SYSTEM

As you may recall from chapter 6, the acquisition part of this sequence of operations



170.47
Figure 7-14.—Control unit for HSPE Mk 1.

could, in such systems as the Mk 56 GFCS, require no more than a very few seconds. With the increasing speed of air targets, it became necessary to shorten the time required for the WLO to communicate target coordinates to the director, and for the director to find and track the target.

In most cases this in effect means transferring target data from one radar system (viz. the broad-beamed search radar) to another (viz. the relatively narrow-focus fire control radar on a specific director). Several systems were soon devised for performing this function. These systems also provide for target designation based on target data derived from visual sightings.

The target designation system doesn't eliminate the necessity for the decisions that must be made in target assignments. What it does (along with the NTDS) is to:

1. Present a complete picture of the AAW situation on which the decisions can be based.
2. Enable target assignment to be made with a minimum of delay, with a maximum of accuracy, and with a positive indication that the director has engaged the designated target.

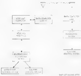


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Figure 7-15.—NTDS data link between ships having NTDS and ships not having NTDS.

Thus any target designation system is essentially a special-purpose high-speed communications and display system, specially designed to perform those functions.

Since there is more than one fire control system and there may be more than one target, deciding which director should track which target can be a difficult decision to make. The officer making these decisions must be quick and responsive to the battle situation. He must keep foremost in his mind the kill capability of the fire control system so designated. He must divide the tracking load between systems as much as possible, and he must have some idea as to which is the more critical target. When (as in a saturation raid) the number of targets is greater than the number of directors and gun mounts, assignment of targets becomes a matter requiring quick, accurate judgment of relative threat from each target and of the ability of each director and gun mount to deal with the targets. In protracted air attack, as in a major strike, such decisions must be made almost continuously.

In the preceding paragraph, we mentioned "the officer making these decisions" without naming his title. This is because control doctrine varies with the ship's weapons installation, depending on whether the target is detected optically or by radar. On ships equipped with a TDS, radar-detected targets are designated to the fire control systems by the WLO and the CIC evaluator who works as a team. The weapons officer in the AAW station topside may intercede in radar designations if he deems it necessary to do so. Most optical designations will come from the weapons officer, but this does not mean that director officers or even mount captains have their hands tied in weapon control matters. In wartime emergencies (as outlined by ship's doctrine) they may even commence firing on their own initiative.

GENERAL DESCRIPTION OF A TYPICAL TDS

Because the Mk 5 TDS shows the steps required for manual or automatic target designation, it will be the equipment discussed in this section. In the Mk 5 TDS, target information (other than NTDS inputs) put into the system originates in CIC (where the target designation station for radar-originated designations is located) and at the AAW station topside (where optical designations originate). The AAW station topside is called Air Defense on destroyers and may be called Sky One or Sky Two on cruisers. Figure 7-16 shows graphically the key points of the system aboard a 931-class destroyer.

The system is controlled from the AAW station and from the target designation station in CIC. Figure 7-17 illustrates the flow of signals through the system. Optical designations are transmitted from the target designation transmitter (TDT) and control unit, through a target designation switchboard to the gun director; radar designations (from local radars or NTDS link) are transmitted from a search radar display on the designation indicator, through a coordinate converter, and through the target designation switchboard to the gun director.

Operators at the designation indicator display (a PPI display) in the target designation station, or operators at the TDT and control unit in the AAW station, track the target and select directors to receive designation.

Each operator at the designation indicator views the search radar and tactical data on the plan position indicator (PPI) display and controls a "joystick" which transmits signals to the video generator and the coordinate converter.

At the converter signals are changed from rectangular coordinates to polar coordinates, and then transmitted through the target designation switchboard to the gun directors.

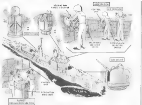

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Figure 7-10. — Target designation system Mk 5 Mod 7, DD 931 class destroyer.

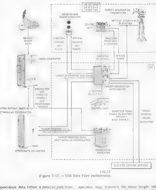

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Figure 7-17.—TDS Data Flow (schematic).

Repeat-back data follow a reverse path from gun directors, through the target designation switchboard, coordinate converter, and video generator, to the designation indicator.

SPECIAL FEATURES OF THE SYSTEM.—The system is a flexible one. Each designation operator may transmit the same target information to one or more gun fire control systems. This allows a maximum concentration of ship fire power. Interdirector transfer is also possible. This can be used to provide increased fire power on a target already being tracked, or

to transfer a target from a director approaching its training limit to a director better able to track on the target.

The system furnishes director repeat-back information on a PPI scope and on indicators that inform designators how long their assistance is required after designations have been made. Luminous semicircles (repeat-back hooks) representing director tracking coordinates are projected on the PPI display. The position of the repeat-back hooks indicates bearing and range from the director.

To avoid duplication of designations, optical designations have priority over radar designations; and optical designations from the starboard side have priority over optical designations from the port side. This permits only one designation to any specific director at any one time.

TDS EQUIPMENT IN CIC

Two of the main units of the target designation system, the designation indicator and the overhead control unit, are located in CIC. These units (fig. 7-18) serve as the display and control center of the CIC TDS station, which is manned by four men — a supervisor and three designators.

The designation indicator has a PPI display and four joysticks (one in each corner) on its top surface and a control panel on one side (fig. 7-18). (The supervisor stands at the control panel.) The PPI display (shown schematically in figure 7-19) includes the following:

1. Bearing dial (calibrated in degrees) and three concentric range markers, permanently marked above and around the PPI tube face.
2. The PPI image originating with the search radar, and including the evolving radar beam, target blips, and other features of the original radar display.
3. Four designate hooks. Each consists of semicircle with a dot at its center. The position of each hook on the display can be controlled by manipulating one of the joysticks.
4. Four repeat-back hooks. These are like the designate hooks, but lack the center dot. The positions of the repeat-back hooks on the display are controlled by selected gun fire control directors.
5. The ship heading marker, which indicates the true bearing of the ship's centerline. As the ship turns, the line revolves around the display.

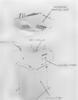

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Figure 7-18. — TDS target designation station.

6. Data manually plotted by the supervisor with grease pencil for use by the designators. The markings are made on a reflection plotter assembly mounted over the face of the PPI scope. This assembly is a nonparallax, concave, partially mirrored surface, so designed that any marks placed on its surface are reflected to the face of the PPI display. The marks reflected downward appear at the same point regardless of the viewing angle.

The overhead control unit is located directly above the designation indicator. It consists of three designator panels and one supervisor panel. It enables director selections and interdirector designations to be controlled from this location. The panels are equipped with director status lamps that indicate the method of designation being used and director selector switches and estimated elevation switches for designating the approximate elevation of the target. (Target elevation is not transmitted automatically.)

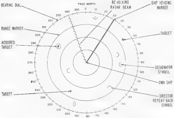

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Figure 7-19.—TDS Designation indicator PPI presentation (schematic).

TDS EQUIPMENT AT THE AAW STATION

All TDS equipment at the AAW station is used for designating targets acquired optically or for indicating the status of the directors (fig. 7-20).

Target Designation Transmitter

The target designation transmitter (TDT) transmits target bearing and elevation data by synchro to the control unit and the target designation switchboard. The TDT is essentially a weather-protected pedestal on which a pair of binoculars can be quickly mounted or dismounted. As the operator manually trains and elevates the TDT to put the binocular line of sight on target and track the target, synchro transmitters inside the TDT pedestal continuously register the position of the line of sight. A pushbutton on one of the TDT's handgrips can be used to signal the target designation station in CIC when the TDT has its line of sight on target. The TDT does not provide for direct transmission of range data; range estimates are normally transmitted from the AAW station's control unit. Two TDT's are installed at the AAW station, one on the starboard side and the other on the port side.

Bearing and Range Indicator

The bearing and range indicator is a multiple-indicating device, consisting of a group of several similar units—one for each director that can receive designations from the TDT's. Each unit has dials which display own-ship course; director bearing and range; the designated values of target position; and an indicator lamp to show whether the director is tracking the target. The indicator

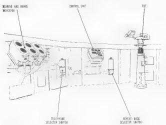

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Figure 7-20.—TDS AAW station.

group is located in front of the AAW officer's station, thus enabling him to monitor the status of the directors.

Control Unit

The control unit is a three dial unit; one unit is associated with each TDT. It displays bearing and elevation information for the TDT and a selected director (one of three may be selected). Signal lights indicate director status. A selector switch can be set to indicate estimated range; this indication is transmitted to the director to which the control unit is switched.

Director Repeat-Back Selector Switch

This switch selects the director to which the control unit is to be connected.

OTHER UNITS ASSOCIATED WITH THE TDS

Other units associated with the TDS include bearing, range, and elevation indicators located in the fire control system directors; indicator panels; a video generator unit; a coordinate converter unit; and a target designation switchboard.

BEARING, RANGE, AND ELEVATION INDICATORS (not illustrated)—located in the gunfire control directors—display designated range, bearing, elevation, and own ship's course. Signal lamps indicate whether the designation is originating with a radar or an optical source.

INDICATOR PANELS (not illustrated) are located in fire control directors; they are used to indicate, by flashing lamps, the source of target designation, and they provide an audible

signal that alerts director personnel to designations.

The VIDEO GENERATOR and COORDINATE CONVERTER (fig. 7-17) are unattended units located in an equipment room near CIC. The video generator provides target information and director data, which are displayed on the PPI scope of the target designation indicator. The coordinate converter has four channels—one per director. Each channel has two sections—an input section and a repeat-back section. The converter receives target information in the form of rectangular coordinates and converts them to polar coordinates, which are transmitted to the directors through the target designation switchboard (fig.7-17). It also converts director data in polar coordinates to rectangular coordinates which are transmitted to the video operator for presentation on the PPI display.

The TARGET DESIGNATION SWITCHBOARD has automatic rotary switches that provide rapid, remotely controlled, flexible switching of target designation and repeat-back circuits. The switches may be operated automatically from the CIC or the AAW station or manually from the switchboard.

FROM TARGET DETECTION TO TARGET DESTRUCTION

Let us now trace the entire process from the moment the target is detected until it is destroyed. Bear in mind that there are many details omitted, and that many steps will be different with different ships and equipment. We are assuming for the sake of illustration that the target designation system is being used with a Mk 56 GFCS and the target information originates with CIC. The entire process is shown graphically in 20 steps in figures 7-21 through 7-31.

If the target information originates in the AAW station, the procedure differs slightly.

The target is assigned to a port or starboard TDT operator to track (fig. 7-32). The TDT operator tracks the target and presses the TDT on-target pushbutton when the target is centered in the binocular. This illuminates the on-target lamp on the associated control unit. The TDT operator keeps this pushbutton depressed during the entire time he is tracking.

The operator at the control unit selects the director to receive the designation and turns the director set-up switch on. This sounds a buzzer to inform director personnel of impending designations. The control unit's "busy" indicator lamp for the selected director flashes. The control unit operator positions the "estimated range" switch to the approximate target range, and sets the director repeat-back selector switch to cause director information to appear on the repeat-back dials.

The director officer accepts designation by pressing the target designation pushbutton, which allows the director to slew to the designated coordinates (fig. 7-33).

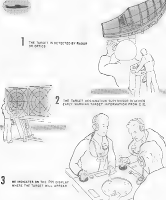
When the radar operator at the radar console has gated the target he presses the footswitch. This shifts the director to automatic tracking, and causes the "tracking" lamp on the control unit to go on.

EMERGENCY OPERATION. If equipment or circuit failure in the radars make normal operation impossible, the TDS can still function to coordinate the target designation operation. By setting a test switch on the video generator so that it develops a "synthetic" trigger pulse (which is normally used in checking and aligning the equipment), the designate and repeat-back hooks can be made to appear on the PPI display. With all hooks properly indicated, even though search radar information is not available, inter-director designation is possible.

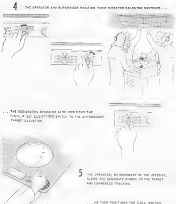
DIRECTOR ASSIGNMENT WITH A WDS

A WDS is basically a TDS. However, it is more sophisticated since more stations and electronic components are involved, and since a WDS controls both missile and gun fire control systems. You'll notice major refinements, particularly in the areas of director assignment and CIC tracking prior to director assignment. One PPI scope did these jobs in the TDS; approximately four separate consoles are used in the WDS. Three of those consoles (those used to track targets prior to director assignment) are called Target Selection and Tracking Consoles (TSTC). The other console is used to make director assignments and is appropriately named the Director Assignment Console (DAC).

A WDS includes all electronic and optical devices used in designating targets. The optical devices are TDTs in the AAW station(s) whose operation we have previously discussed. The electronic devices are all part of a sub-equipment called the Weapons Direction Equipment (WDE). A WDE has as its major units the four consoles mentioned above and another console called the Weapon Assignment Console (WAC). The WAC has no designating function. Its purpose is to provide a means for assigning the missile

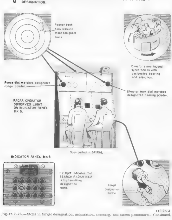


110.78.1
Figure 7-21.—Steps in target designation, acquisition, tracking, and attack procedure.



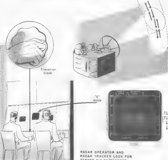
110.75.2

Figure 7-22.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.



110.78.3
Figure 7-23. — Steps in target designation, acquisition, tracking, and attack procedure — Continued.

7 IF PIP DOES NOT APPEAR WHEN RANGE, BEARING, AND ELEVATION HAVE BEEN SYNCHRONIZED, RADAR OPERATOR SEARCHES IN ELEVATION WITHIN ±20° OF DESIGNATED VALUE.

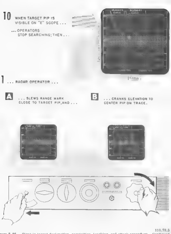


8 IF PIP DOES NOT APPEAR DURING ELEVATION SEARCH, RADAR TRACKER SEARCHES WITHIN ±20° OF DESIGNATED BEARING.

9 IF PIP DOES NOT APPEAR DURING BEARING SEARCH, RADAR TRACKER PRESSES "SEARCH ERASE" BUTTON TO RE-SYNCHRONIZE SYSTEM. THEN BOTH OPERATORS REPEAT ELEVATION AND BEARING SEARCHES.

110.78.4

Figure 7-24.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.



110.78.5

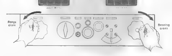
Figure 7-25.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.

12 AS SOON AS PIP IS VISIBLE ON "B" SCOPE . . .

. . . RADAR TRACKER . . .

A . . . CRANKS RANGE TO CENTER PIP VERTICALLY, AND . . .

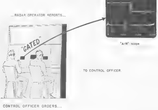
B . . . CRANKS BEARING TO CENTER PIP HORIZONTALLY; THEN . . .



13 . . . PRESSES SCAN CONTROL FOOT SWITCH TO SHIFT TO CONICAL SCAN FOR AUTOMATIC RADAR TRACKING

110.78.5
Figure 7-26.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.

14 WHEN TRACKING CIRCUITS "LOCK ON" PIP...



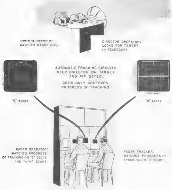
15 CONTROL OFFICER ORDERS...

16 DIRECTOR OPERATOR RELAYS MOUNT CAPTAIN'S REPORT OF "MOUNT 52 IN AUTO" TO CONTROL OFFICER THROUGH VOICE TUBE.

110.78.7

Figure 7-27.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.

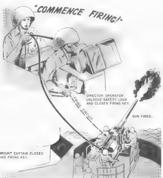
17 AUTOMATIC RADAR TRACKING



110.78.8

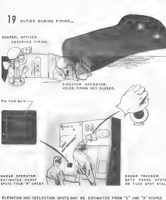
Figure 7-28.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.

18 WHEN "OPEN FIRE" RANGE IS REACHED, CONTROL OFFICER ORDERS...



110.78.9

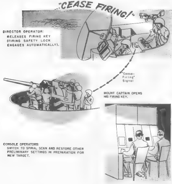
Figure 7-29. — Steps in target designation, acquisition, tracking, and attack procedure — Continued.



110.78.10

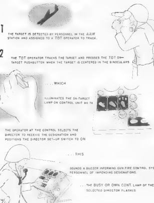
Figure 7-30.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.

20 WHEN CONTROL OFFICER OBSERVES THAT TARGET IS DESTROYED OR HAS PASSED BEYOND EFFECTIVE FIRING RANGE, HE PULLS CEASE FIRING HANDLE AND ORDERS...

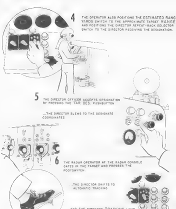


110.78.11

Figure 7-21.—Steps in target designation, acquisition, tracking, and attack procedures—Continued.



110.79.3
Figure 7-32. — TDS steps in target designation procedure (AAW station).



110.79.2
Figure 7-33. — TDS steps in target designation procedure (AAW station). — Continued.

launcher (an act which is similar to putting guns into automatic) and to fire the missile at the optimum time.

Keep in mind that many weapon direction systems are linked to naval tactical data systems. Therefore, they may receive designations from externals sources (fig. 7-15).

GENERAL DESCRIPTION OF A WDS

Don't be dismayed by the abbreviations in the preceding article. They will become commonplace if you are assigned to the weapons department of a missile ship where these terms (and their abbreviations) are used.

Figure 7-34 shows the major units in a WDS that are used in radar designations (some were eliminated for simplicity). Notice that a missile fire control director and its computer, and gun fire control director and its computer, are depicted along with their respective delivery devices; i.e., a missile launcher and a gun. You'll recall that once a target is acquired by a fire control system, the system functions independently of the WDS in tracking the target, and in computing the launcher or gun orders. The function of the WDS, then, is to direct the fire control system to the target initially.

An air search radar detects targets and sends the video data simultaneously to three TSTCs. The TSTC in CIC selects the targets to be tracked by the other two TSTCs in the weapons control station. This is done by assigning electronic tracking channels to the targets. A tracking channel is assigned to a target based on evaluation by the CIC evaluator and the WLO. Each TSTC operator in the weapons control station has a prearranged responsibility for establishing a track in one-half of the total number of channels—a division of the tracking load results. A target movement rate is electronically available within a channel after a few seconds of manual operation by a TSTC operator. The established rate enables the TSTC to track the target automatically as long as relative motion factors are constant. Additional minor corrections are required by the operator if the relative motion factors vary. Tracking channel data are sent automatically to the director assignment console. These data include range, bearing, course, speed, altitude, and estimated weapon release range for as many targets as are being tracked. The system can track as many targets as the number of tracking channels permits.

It is from the director assignment console (where all target data are collected and displayed) that a specific director or fire control system is selected to destroy the target. The selected director slews (i.e., moves at an accelerated rate) to the target's present position in range, bearing, and elevation. If all equipment is aligned and functioning properly, the target echo is now visible on the fire control system's radarscopes. The crew refines director position and causes the fire control system to shift into automatic radar track. When a system shifts into automatic track, its associated computer starts computing precise gun or launcher orders. Synchronizing a gun to its ordered position, and its subsequent loading and firing are processes that are controlled by the system's director officer. Loading a launcher, synchronizing it, and firing the missile are steps that are supervised by the WAC operator (nominally, the missile officer). Control doctrine normally requires these officers to receive orders from the ship's weapons officer before firing ordnance.

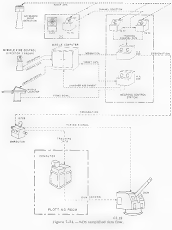
We'll now take a closer look at the operation of a TSTC, and in the following section, a DAC. The WAC will be covered in the second volume of this series. Even though figure 7-34 is representative, it does not show the exact number of WDS units installed on all missile ships. The number (and the location) of these units depends on the ship's armament.

THE TARGET SELECTION AND TRACKING CONSOLE

There is a typical TSTC and its PPI display in figure 7-35. If this were the one in CIC, it would be controlled by an assigned operator who is under the direct supervision of the WLO. The console displays targets on PPI presentation which can be shifted to monitor various radar search displays. Shifting of the radar display permits system flexibility in the event of malfunction or poor reception of any one search radar. If the air search radars are equally receptive, the console operator will select one that has a height-finding capability and the narrowest radar beam.

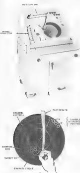
As mentioned previously, the target height quantity is eventually converted into an angle of true target elevation for use by the directors. We observed that this eliminated large sector searching in elevation by the directors and therefore greatly reduced target acquisition time.

Using the search radar that has the narrowest beam further reduces target acquisition time in that it more definitively pinpoints the target's position. Search radars have a much larger beam width than fire control radars. This means that



63.19

Figure 7-34.—WDS simplified data flow.



12.42
Figure 7-35.—A. Typical target selection and tracking console; B. TSTC display.

a certain amount of refining or searching by the fire control director is required after it has been designated to a target by a relatively broad beam search radar. Correct radar alignment reduces the searching requirement.

Any one of the three consoles can be used to send target data to the DAC. In practice the WLO's TSTC is used to alert the other two to the threat of an attack. That is, the WLO's console will select the target to be tracked and the other two consoles will do the actual tracking.

Target selection is accomplished by placing the pantograph arm on the console directly over the target video on the radarscope. A small illuminated dot, which represents the position of the pantograph arm, will then be superimposed on the target video. If evaluation indicates that the contact is a threat, the WLO will order his console operator to assign a tracking channel to the target.

There are a number of tracking channels in this equipment. Several tracking channels are necessary in order to separate the movement data of one target from another when the console is used to track multiple targets. Buttons which activate the tracking channels are located on the left of the console and identified by single letters such as A, B, C, etc. To activate a tracking channel for a particular bogey, the operator presses a channel button which is not in use. A small illuminated circle with the channel letter designator within will then appear in the same position on the radarscope as the dot from the pantograph arm.

The two target selection and tracking consoles in the weapons control station have more or less the same radarscope picture as the console in CIC. Tracking channel C for example, shows up in exactly the same position on all three consoles provided the individual console controls are set alike. Disparities in console presentations occur when different range scales or radars are selected by the console operators. However, the true position of both the symbols and targets is unaffected by the console controls.

To reiterate, the presence of a tracking channel symbol superimposed on target video will cause the tracking operators to commence tracking that particular target. Upon assigning a channel to a target, the console operator in CIC parallels visible information via sound-powered telephones. It is in this way that the WLO can select the target to be tracked by weapons control.

The evaluator or WLO estimates the target's weapon release range and the console operator manually inserts it into the system. Insertion of EWRR (estimated weapon release range) is

accomplished at the WLC's console by pressing the appropriate channel button and simultaneously making the input at an attached panel. This channel circuit activating prerequisite permits each tracking channel to have its own EWRR. Knowing the target's EWRR aids weapons control in making a director-to-target assignment. This is particularly true if multiple targets have been detected.

Pre-battle intelligence relating to the enemy's aircraft types and weapon capabilities should be available to the evaluator. Studies will have to be made, based on all available information, to provide EWRRs for different aircraft types. Standards will have to be developed for use in the absence of target amplifying data. The evaluator, who is a very busy individual, may delegate the determination of EWRR to the WLO. In any event, the WLO is responsible for its insertion into the equipment.

WDE designation-accept circuitry has no way of knowing automatically which search radar is being used by the target selection and tracking consoles. This presents a problem when search radars without height-finding capabilities are the source for target designation. Obviously, target height data in this case are unreliable. Some means is then necessary to inform control personnel and increase the limits of the fire control directors' elevation search area. A switch, activated by a target selection and tracking console operator, will illuminate "elevation unreliable" lights throughout the system. The same switch triggers computers which then enlarge elevation search in missile directors during the acquisition phase. Throwing this switch is unnecessary on destroyers because the absence of height data automatically activates elevation unreliable circuits.

We mentioned before that the WLO selects the target to be tracked by weapons control. Actually his is a mechanical selection which is an execution of the evaluator's tactical selection. In the heat and confusion of battle, however, these two individuals may often find their responsibilities overlapping. It is mandatory that the evaluator and WLO work together as a team. The WLO will sometimes be required to take control of weapon direction when the evaluator is involved in another facet of this extremely complex battle station. An alert WLO may observe a threat on his radarscope that is not displayed on the phase 2 plot. He can also anticipate the evaluator's decision and assign inactive tracking channels to suspected threats. This does not mean it is time to start shooting. The WLO is merely establishing a TS and TC track on the contact.

Tracking at the target selection and tracking consoles is rate-aided. That is, a target movement rate is established which subsequently aids the operator in tracking. The rate is generated by repositioning the pantograph arm to coincide with the target's movement. When the pantograph arm is moved, and a rate-aid switch is activated, present target position data are inserted into the tracking channel. Successive changes of pantograph position are electronically compared with previous positions and a target rate is the eventual result. The continuous rate-aided solution will then keep the channel letter designator positioned on target. Three or four pantograph corrections should be all that are needed to establish a fairly accurate rate. Minor corrections are necessary as the track progresses to compensate for changes in target course, altitude, or speed. Rate-aided tracking pays off since multiple targets can be tracked with one tracking console using one pantograph device.

The operators of the two tracking consoles in WCS are responsible for tracking in channels to which they have been assigned. The practice is to assign half of the channels to each operator. It is then up to the selecting console in CIC to split up the tracking load. A tracking operator can insert target data into a channel only if he has access to that channel. We are speaking now of electronic access and not predetermined responsibility. Channel access is electronically indicated by the presence of a small circle around the channel letter designator on the radarscope. A tracking console operator can gain access to a channel through a switch on the pantograph arm or by pressing the desired channel pushbutton.

It is possible to display access circles for a particular channel on more than one console and for more than one operator to make alternate corrections to the channel's rate. It is not possible for more than one operator to make rate corrections simultaneously in that particular channel. In the event simultaneous inputs are attempted, an electrical order of precedence takes over and permits the channel to receive data from one source only. The console with the highest precedence is understandably in CIC. Precedence is also established for the two consoles in WCS.

Target height or altitude gradations are inscribed toward the left on the radarscope of each

target selection and tracking console. These graduations or indices increase from bottom to top on the scope with each increment equal to 5,000 feet. If a 3-coordinate radar has been selected at the console, a video dot representing the target's height will appear adjacent to the height graduations. The video dot moves vertically in response to target height information from the radar. Target height is then visually apparent to the operator when he compares the dot's vertical position to the inscribed indices.

To put height into a channel, the operator gains access, rotates a height cursor knob to align a height measuring spot on the scope to the vertical position of the video dot, and then operates a "height data in" switch that stores height into the channel. If a 3-coordinate radar is unavailable, the equipment can continue to send height data to the WCS provided height has been received in GEOREF report. The known height data are substituted for the vertical position of the video dot. The height cursor knob is rotated until the measuring spot agrees with the reported height and the rest of the operation remains the same. Height data from another ship are not as accurate as that received from our own ship's radar, therefore the console operator throws a switch that energizes the "elevation unreliable" circuits, except for destroyers where this is unnecessary.

THE DIRECTOR ASSIGNMENT CONSOLE

Assinging the proper director in time is very important in AAW. The officer operating the director assignment console must be extremely well qualified. He must be aware of tactical considerations, and be able to comprehend the electronic difficulties which sometimes beset this very complicated equipment. His electronic knowledge must extend to all phases of director assignment and the director's ability to receive designations.

Tracking data from a channel are fed automatically from the tracking console into the director assignment console. Two plots or scopes are provided on this console. They are called the plan and multipurpose plots (fig. 7-36). Target video is not present on these plots, but the plan plot shows target range and bearing by displaying the same channel letter designators we have discussed before. Target course and speed for a particular channel can be approximated on the plan plot by a vector which has its tail attached to the channel letter. The vector's magnitude and direction correspond to target speed and course. (See channel A in plan plot.)

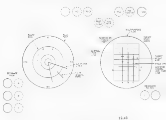
Numbers which show the range and bearing of the directors are also displayed on the plan plot. The director numbers are always present but a channel letter shows up only when that channel is used to track a target. All of the symbols (numbers and letters) are intensity modulated: that is, they show up on the scope as a video presentation. The directors are numbered in increasing numerical order from forward to aft on the ship. All directors that are used in AAW have their numbers displayed on the director assignment console. The director numbers are also displayed on the target selection and tracking consoles provided the director is tracking. If director 1 is tracking channel B, a 1 would be superimposed on the B.

The plan plot also presents a ship's heading mark, which is a continuous indication of own ship's course. There is a radial line on each side of the heading mark that also moves in response to course changes. The arc described between the radial lines through the ship's head marker represents the missile blind zone for an after launcher installation.

The multipurpose plot is used for making time comparisons which enable the operator to select one of several targets for designation to a director. This plot permits the operator to plan ahead in case the directors are occupied and cannot be assigned immediately. Target height and speed are also displayed on this plot to aid the operator in director assignment.

The multipurpose plot has a vertical video line for each tracking channel. The vertical length or height of the line is compared to inscribed indices on the scope which represent time. The vertical time lines are "programmed" to show when a director must be designated to a particular channel, so that a missile may be fired to intercept before the target reaches his estimated weapon release range. The factors which affect the height of the vertical line are target range and speed, fire control director acquisition time, weapon assignment time, and EWRR. Computations for these lines are based upon their application to missile fire control systems; however, approximations can be made which will apply to gunnery fire control systems as well.

Pushbuttons on the left side of the director assignment console are used to "designate from" a target data source. The source may be any one of the tracking channels, one of the optical target designation transmitters (TDTs), or one of the AAW directors which has previously acquired



12.43

Figure 7-36.—Director assignment console display.

the target. Your ship may have two or four TDTs located at topside AAW station(s). TDTs are used to designate targets which may have escaped radar detection. Designating from a director to another director is called inter-director designation; it is by far the most expeditious method, since the target is more accurately pinpointed by fire control radar.

Pushbuttons on the right side of the console are used to "designate to" a fire control system. There is a pushbutton for each AAW director arranged in numerical order from top to bottom on the console.

To assign a director to a target data source, the console operator merely presses a "designate from" simultaneously with a "designate to" push button. For example, if we wish director 1 to track the target in channel C, we would depress the C in the "designate from" column and the 1 in the "designate to" column simultaneously. If we want director 1 to track director 2's target, we would depress the 2 in "designate from" along with the 1 in "designate to." (The total number of directors and data sources is not shown in figure 7-36.)

Circuits are then activated which automatically slew the director to the target in range, bearing, and elevation. Remember, the accuracy of the elevation information depends on the reliability of target height data. Range and bearing accuracy depends primarily on the tracking ability of the target selection and tracking console operator. We are assuming that your equipment is aligned and functioning properly.

A director is released from designation when it "sees" the target with its own equipment or when the DAC operator presses a designation "release" pushbutton on the right side of the console. The "release" pushbutton will have to be depressed at the same time as the director's "designation to" pushbutton.

A tracking channel is "dumped" by using more or less the same procedure. Another release button, on the lower left of the console, must be depressed simultaneously with the pushbutton for the channel that is no longer desired.

A tracking channel can also be dumped at the target selection and tracking consoles by using the same procedure; however, a good practice would be to dump channels only from the director assignment console. Undesirable accelerated movement at the director may result if a channel is dumped when the director is attempting to acquire the target. For this reason it seems advisable to dump channels from the DAC, since it is the only console where director acquisition of the target can be viewed. As you will recall, the director's number is not present on the target selection and tracking consoles until the director shifts into the track mode.

An ever-present problem in weaponry is the limitation placed upon firing arcs by the ship's superstructure. For obvious reasons, launchers and guns are electrically cut out if they are aimed at any part of the ship. The cutout area in bearing and elevation is referred to as the blind zone for a specific weapon. An after launcher cannot fire dead ahead and a forward gun is cut out directly aft. The blind zone problem is still present even when similar weapons are located fore and aft, provided an attack is overloaded in one direction. The director assignment console operator solves this problem by making course recommendations to the pilot house. Maximum fire power will be brought to bear if the ship places her beam to the expected attack, however, this is not always feasible. To recommend a course, the director assignment console operator rotates a "course recommend" knob to the desired course, activates a "course recmd" switch, and an electrical signal positions a course indicator in the pilot house. Course recommendations are paralleled via the JA telephone circuit for general information and to give the officer of the deck an opportunity to intercede if the new course would endanger the ship. In making course recommendations, the DAC operator must consider the dead time before a steering order is given and the time it takes the ship to complete the maneuver. A course is recommended generally as soon as the target's projected track indicates that he will enter the blind zone.

CHAPTER 8

INTRODUCTION TO GUN BATTERY ALIGNMENT

This chapter takes up the elements of gun battery alignment, explaining the principal operations required in aligning the equipment and maintaining it in alignment.

Battery alignment is one of the critical factors in the fighting effectiveness of any combat ship equipped with guns or missile launchers. Without proper battery alignment the projectiles and missiles fired will not hit their target when properly aimed—regardless of high crew efficiency, high-power radar and optical equipment, speedy fire control computation, or high rate of fire. Maintenance of accurate battery alignment is a primary responsibility of weapons personnel, beginning when the ship is under construction, continuing so long as it remains in commission—even when the ship is retired to the "mothball" fleet. Battery alignment is not confined to operations at infrequent intervals. Although some alignment operations are performed as infrequently as once every two years, some operations (such as transmission checks) are done every day.

Taking into account in detail all the phases of battery alignment, beginning with the original construction of the vessel, it is evident that the subject is complex and requires close study even by the nonspecialist. This chapter concentrates on principles rather than procedural details, and on alignment afloat, rather than the more complex drydock operations.

BATTERY ALIGNMENT: PURPOSE, DEFINITIONS AND DISTINCTIONS

The purpose of battery alignment is to adjust the guns of the battery and associated fire control equipment so that the lines of sight of the director telescopes and gun sights, the beam axes of the radar antennas, the lines of sight of optical rangefinders, and the bore axes of the guns in the battery, are all parallel when

1. dials are matched with correct follow-the-pointer indications,
2. no parallax corrections are introduced, and
3. no ballistic corrections are introduced.

In a correctly aligned system, all associated gun bores, etc. remain parallel under these conditions throughout all operating motions, and all instrument dials and automatic control equipment measure these motions correctly with respect to the proper reference.

To accomplish this, all these elements must be aligned to a common system of reference points, lines, and planes. Battery alignment can therefore be defined as the process of adjusting all the elements of a weapon system (in a gun battery this includes the director, sights, radars, computer and stable element if any, and the gun mount sights and gun barrels) to these common reference points, lines, and planes, and maintaining them in this relationship.

Note these distinctions:

INTERNAL ALIGNMENT refers to adjustment of the geometrical relationships within an element of the fire control or weapon system, such as a mount's gun bore axis and the mount's gunsight mechanism.

SYSTEM ALIGNMENT refers to the geometrical relationships between two or more major components of a system, for example the bore and sight telescope axis of a gun mount as related to the line of sight of director telescopes.

ORIGINAL ALIGNMENT is the initial alignment made in a fire control and weapons system at the time of original construction and installation. This is a very elaborate and highly accurate series of operations done in drydock by the shipbuilder or fitting-out yard. Original alignment is also performed whenever a new or modified major weapon system is installed (also usually a drydock operation).

DRYDOCK ALIGNMENT OR REALIGNMENT refers to the thorough alignment overhaul and readjustment made when a ship goes through its

regular drydock overhaul period, at intervals usually of two years or longer.

ALIGNMENT AFLOAT refers to alignment operations performed while the ship is waterborne (in port or underway). These operations are performed much more frequently than the relatively elaborate drydock alignment work. Alignment afloat requires standards of accuracy just as high as those of original alignment. The main difference is that alignment afloat must be performed by weapons department personnel with equipment available on the ship.

TRAIN ALIGNMENT refers to adjusting fire control and weapon system elements so that they are in effect all parallel and are all at exactly the same angle to a selected vertical plane.

ELEVATION ALIGNMENT refers to adjusting these elements so that they are parallel and are all at exactly the same angle to a selected horizontal plane. In both cases, alignment as defined assumes that no ballistic corrections or parallax corrections have been introduced. Train alignment is commonly performed separately from, and before, elevation alignment.

ALIGNMENT ERRORS AND THEIR SOURCES

In alignment operations, errors and discrepancies can be traced back to three sources:

1. Human error (observation error).
2. Instrument error (mechanical error).
3. Lost motion.

Human error is caused by factors such as failure or inability of operating or maintenance personnel to match index marks or graduations; tendency to misread, or to read with limited accuracy, scale indications; failure to line target points up exactly with reticle crosshair intersections; and the like. This is necessarily caused by personnel incompetence; incompetence or carelessness may increase this source of error to serious proportions, however. Even the sharpest-eyed, most skillful, and most conscientious person has his limitations. To keep adjustments and observations as free of human error as possible under the usual conditions aboard ship, working personnel take the following precautions:

1. Each observation or measurement is made as carefully as possible. This requires that the operation itself be carefully prepared and performed. It is important also to use care in reading dials—to count the graduations accurately, and to look at the dial squarely to avoid apparent displacement (parallax effect) of the index or pointer and the graduations.

2. Critical measurements are taken two or more times, and the recorded value taken is the mean (average) of these.

3. Especially critical observations may be taken not only more than once, but by a different individual each time.

Human error may be consistently in one direction and variable in amount, or (as is rather more common) consistent neither in direction nor amount.

Instrument error (often called mechanical error) is caused by some kind of incorrect setting or relationship in the equipment. It may be caused by incorrect adjustment of a part, or wear, or weakening of a spring, or warping of a shaft, or any number of other causes. Such errors may also be caused (in electrical or electronic equipment) by failure or weakening of a tube or capacitor, or other electrical malfunction. As distinguished from lost motion (see below), instrument error is generally consistent in direction and magnitude. When combined with the effects of human error and lost motion, this characteristic may be obscured.

Lost motion is normally caused by wear and deterioration of parts through either use or lack of use. The term applies to looseness or slackness of linkages of all kinds, whether caused by faulty or sloppy engagement of gears, excess end play or shafting, weakening or failure of springs, or other causes. A mechanism may, because of wear or other causes, bind or stick in some ranges of its operation while it has lost motion in others. A minimal amount of lost motion, like a minimal amount of human error, is in most mechanisms impossible to avoid (though spring loading can in some applications reduce it to zero), and designers provide for such minima by necessity. But lost motion must be taken up by resetting of parts, and replacement of worn parts, as required during repair work.

In certain operations, maintenance personnel can virtually eliminate the effect of lost motion (but not lost motion itself) by approaching each critical observation or reading from a given direction. When doing this, if you overshoot, begin again and approach the desired value from the same direction. But if you are measuring

lost motion or actual instrument error itself, you approach first from one direction and then the other, taking a series of readings and averaging to ascertain the values you seek. See the section on alignment afloat for an example of this technique.

Note that these three main types of error don't register separately; they are all nearly always present in some degree. The observations and readings you get include the effects of all three. The effects may either be additive, increasing the net error, or subtractive, partially canceling out and reducing the net error.

INTERNAL ALIGNMENT OPERATIONS

The internal alignment operations that are normally considered within the scope and responsibility of a weapons department aboard ship include the following:

1. Gunsight alignment (which includes boresighting).
2. Tramming (defined later in this section).
3. Bench mark checking.
4. Director sight alignment.
5. Synchro zeroing.

The first two of these (gunsight alignment and tramming) are performed on gun mounts and turrets; numbers 3 and 4 are performed on fire control directors; and the last is done with nearly all synchros. No internal alignment (within the meaning defined earlier in this chapter) is performed on fire control computers or stable elements.

The five types of alignment operations listed above are not the only internal alignment operations that may be required; they are simply the types of alignment operations that can normally be performed afloat by the ship's force. There are other internal alignment operations that may be required in drydock or during ship construction or major alteration. These include aligning the gun trunnions; shimming the director, mount, or turret roller paths to eliminate warping; installing bench marks and tram blocks; and the like. All of these require either the lifting of major armament units like turrets or mounts, or extensive resurveying of the fire control installation's geometry, using special procedures and equipment such as theodolites and transits which are not normally carried aboard combat ships. Operations such as these are not described in this book; they are described in OP 762, Alignment of Ordnance Installations Aboard Ship.

GUNSIGHT ALIGNMENT

Gunsight alignment is that part of battery alignment which involves the mechanical alignment of the parts making up each element — namely, alignment within each mount, turret, or gun of the battery. Gunsight alignment is usually the initial step in battery alignment, and consists of three procedures:

1. BORESIGHTING. The pointer's and trainer's telescopes do not lie on the axis of the gun's bore. For firing at short ranges in local control, they must, therefore, be aligned so that their sighting axes intersect the extension of the bore axis at the target. Since the gun bore is only a few feet from the sights, the error which may be caused by parallel alignment is very small. Thus, gunsights may be aligned either to mean battle range for the battery involved or along parallel lines (converging at infinity).

2. CHECKING FOR LOST MOTION. The values of sight angle and sight deflection as set on the sights must not contain inaccuracies due to lost motion in the sight mechanism.

3. CHECKING FOR PARALLELISM OF SIGHTS. Sight angle or range settings must elevate or depress the sighting axes of the telescopes in a plane perpendicular to the trunnion axes, and deflection settings must move the sighting axes of the telescopes in a plane parallel to the trunnion. In other words, the sights must be aligned for parallelism. This is not normally performed during alignment operations while afloat.

Boresighting

The object of boresighting is to make the sight axes and the bore axis converge at either (1) a specified range or (2) infinity, with the range scale and the deflection scale reading their zero value in either case.

In order to adjust the sights in this manner, a boresight telescope must be used. This is a telescope that may be mounted in the bore of a gun and adjusted so that its line of sight coincides with the axis of the bore. Then by sighting through this telescope and through the sight telescopes simultaneously, the latter may be adjusted to obtain convergence or parallelism.

There are two main types of boresights: the breech-bar type and the type with self-contained optics.

A breech-bar boresight consists of (1) a boresight telescope, (2) an adapter for installing the telescope in the gun, and (3) a muzzle disc used for aligning the telescope on the axis of the bore. With bag-type guns, the adapter takes the form of a breech bar that can be installed across the screw box. A breech-bar boresight can also be used for boresighting a 5"38 gun, but with a different type of adapter. The same boresight telescope can be used in boresighting guns 5 to 8 inches in caliber (except the dual-purpose 6"/47 and the rapid-fire 8"/55), if provided with the proper adapters and muzzle discs.

Boresights with self-contained optics vary in construction, and even in principle of operation, from those that consist merely of a fitting with a small hole for the breech end and another with a pair of crosshairs at the muzzle end to those that convert the gun into a huge (but low-power) telescope. Boresights with self-contained optics are designed to fit specific guns; no parts of them are interchangeable between guns.

The boresighting process with either major type of boresight is substantially similar, except that breech-bar boresight telescopes must first be aligned on the gun bore axis by sighting on the muzzle disc. This step is not necessary when using boresights with self-contained optics. This section describes boresighting with a breech-bar boresight, because it requires this extra operation. Otherwise, once the self-contained optics boresight is installed, the procedure is exactly like that for breech-bar boresights (described later).

Boresight Apparatus: Breech-Bar Type

The equipment required at the gun to boresight a bag gun includes —as noted in the preceding paragraphs —a breech bar, a boresight telescope, and a muzzle disc. The equipment and method of mounting on a gun are shown in figure 8-1.

The breech bar is a precision-machined bar which can be attached to the face of the breech by two screws. There is a hole through the midsection to receive the outer tube of the boresight telescope.

The boresight telescope tube is mounted within an outside adjusting tube which screws into the breech bar and is locked by means of the locking ring. Within the adjusting tube, the telescope is mounted in a spherical bearing which permits the telescope to be adjusted in both the horizontal and the vertical plane by means of four adjusting screws, so that the axis of the telescope can be made to coincide with the axis of the bore. The telescope has three rings near the eyepiece: (1) the reticle focusing ring for focusing the eyepiece to the individual eye, (2) the objective focusing ring for focusing the telescope on the target and eliminating parallax error (apparent target displacement when the eye is shifted about the optical axis of the eyepiece), and (3) the rotating ring, which permits rotation of the telescope about its axis within the outer adjusting tube.

The muzzle disc is a circular casting designed to fit snugly in the muzzle of the gun. Through the center of the disc is a small hole, and around it are four larger holes, arranged as shown in figure 8-1. Etched rings around the edge of the disc provide means for fitting the disc in the muzzle perpendicular to the axis of the bore. Notches are engraved on both disc and gun as index marks. With these index marks matched, one row of holes is aligned vertically and the other horizontally with respect to the gun. The purpose of the disc is

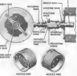


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Figure 8-1.—Boresight apparatus.

merely to assist in the alignment of the boresight telescope axis with the bore axis.

Once aligned, the muzzle disc is removed and has no further part in the boresighting of the gun until the final stage, when it is remounted for a recheck of alignment to assure that no error has crept in during the process. Boresights with self-contained optics do not require the use of a muzzle disc in obtaining alignment with the bore axis.

Boresighting Preparation

The general steps necessary in getting the gun ready for boresighting are as follows:

1. Ascertain that the pointer's and trainer's scopes are clear, focused, and free from parallax.
2. Remove all evident lost motion from the sight mechanism (refer to the section on "Looseness of Parts and Lost Motion" that follows).
3. Lash back the breech plug so that motion of the ship will not swing the plug against the boresight apparatus. (For case guns, make sure that the breech block is securely held down.)
4. Install breech bar, boresight telescope, and muzzle disc. (For boresights with self-contained optics, only the boresight components are installed. No muzzle disc or breech bar is required; therefore steps 5 and 6 below are unnecessary.)
5. Focus the boresight telescope and center the crosshairs on the small center hole in the muzzle disc, using the four outer holes to align the crosshairs vertically and horizontally.
6. Remove the muzzle disc.
7. Set the range scale at zero (sight angle scale set at its zero value —usually 2,000 mils) and deflection scale at the midpoint (usually 500 mils).

Choosing A Target

A target with a clearly defined and visible point is suitable for boresighting in both deflection (train) and elevation. In the absence of such a target, two targets may be used: one with a clear vertical line of boresighting in deflection, and one with a clear horizontal line for boresighting in elevation.

If the guns are being readied for a specific gunnery practice, the target selected should be at the range specified for that practice. For general use a target should be chosen at about the range at which the guns being boresighted are most effective, called the mean battle range. Or, if a parallel alignment is desired, a distant target like the moon or a star may be chosen. When the moon is used it is called "shooting the moon." For elevation only, the horizon often makes an excellent target, especially for such guns as the 5-inch and 6-inch, for which it roughly corresponds to mean battle range.

Looseness of Parts and Lost Motion

Before beginning the actual boresighting, check for looseness of parts and for lost motion in the gunsight mechanism.

To check for looseness of parts, first sight on some convenient target. Then manually shake all adjustable parts, and recheck the crosshairs on the target. If the sights are off, tighten the linkage and try again. This check should be performed independently for the trainer's and pointer's telescopes.

To check the sight mechanism for lost motion, set the sights so that the crosshairs are on a target whose position with respect to the gun remains fixed. Use a point on the ship itself or, if the ship is in drydock, a target outside the ship. While this check is going on, keep the gun stationary.

Set the sights at maximum range on the range scale and then return them to their original setting. If there is no lost motion, the horizontal crosshair will return to its exact position on the target. Make a similar check for the vertical crosshair by setting maximum sight deflection, returning to original deflection setting, and observing change due to lost motion, if any.

If there is lost motion in the sight mechanism, it can be removed by taking up excessive play or clearance between moving parts.

Boresighting The Gun

To boresight in train, bring the gun to bear on the target so that the vertical crosshair of the boresight telescope is aligned with a vertical mark on the target. As the ship pitches and rolls, at the instant when the boresight is on, the man at the boresight calls "mark." If the pointer's and trainer's vertical crosshairs are not on target at this instant, adjust the sight deflection input coupling to the telescopes until all vertical crosshairs are on at "mark." Similarly, to boresight in elevation, align the horizontal crosshair of the boresight telescope with a horizontal mark of the target. Adjust the sight angle input coupling to the telescope until all telescopes are on with the boresight telescope.

The sight checker's telescope should also be adjusted in both deflection and elevation.

After boresighting, recheck for looseness of parts. Before securing, place the muzzle disc in the gun (applicable to breech-bar boresights only) to make sure that the boresight line of sight is still coincident with the axis of the bore. If it is not, boresighting must be repeated.

Checking Parallelism of Sights

As mentioned earlier, this is not normally performed as a separate operation except while the ship is at a shipyard, and it will therefore not be detailed here. In one method of performing this check, a flat wooden screen with suitable target markings (called a batten) is secured to the gun barrel near the muzzle, and the parallelism of the sights is checked by observing how accurately the sight reticles follow the target markings as the gun is elevated and depressed.

The boresighting procedure for an infinitely distant target, as described above, adjusts the sights for parallelism with each other as well as with the bore axis.

Other Boresighting Methods

Except for the alignment steps requiring use of the muzzle disc, the boresighting method using self-contained optics boresighting resembles the method described above. Boresighting at battle range rather than infinity is common for smaller gun mounts; this requires either selection of a target at suitable range or the use of marked batten boards mounted on the deck. The batten board method is used relatively rarely and will not be described here.

Tramming

When you measure gun elevation and train, you specify the angle between the axis of the gun bore and a plane parallel to the selected horizontal reference plane (for elevation angle), or between the axis of the bore and a plane through the centerline of the ship and perpendicular to the selected horizontal plane (for train angle).

When a gun mount or turret is installed, its train angle and elevation angle are very carefully measured at selected gun mount positions. The selected positions for train and elevation are accurately designed by metal markers or tram blocks welded to the structure of the gun mount. These selected angles of elevation and train are recorded in the battery or mount log, and remain on record so long as that ordnance installation remains on the ship. Tramming is the procedure for verifying that when the mount or turret is positioned at the selected angles, the train and elevation indicators display the values prescribed. There is but one elevation angle and one train angle at which any individual mount or turret can be trammed.

Tram blocks are steel blocks welded to the mount structure in pairs, one pair for elevation, one for train. Figure 8-2 illustrates 5"/38 tram block arrangement for a single mount. One of the pair of blocks for elevation is secured to the mount carriage (which does not move in elevation); the other of the pair is secured to the slide (which does). Similarly, one of the pair for train is welded to the mount base ring, which moves in train; the other is welded to the stand, which is secured to the deck. Tramming in train is one operation and tramming in elevation another. These operations are performed successively. Only one tram is used at a time, not two at once.

A typical tram block for a 5"/38 mount is shown in cross section in figure 8-3. Imbedded in the block is a short steel rod whose outer end is cupped to take the tram. The tram block face is covered with a metal cap and packed with grease to prevent corrosion. The block is uncovered only for tramming, and is repacked when the cover is replaced.

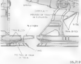

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Figure 8-2.—Tramming a 5"/38 single mount in elevation and train.

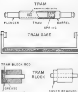

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Figure 8-3.—Tram, tram gage, and tram block.

The tram itself has two rounded ends. One is part of the body or barrel, and the other is part of the spring-loaded plunger that can move within the barrel. Across a small window in the barrel is an index line. A line on the sleeve is matched up with the barrel index line by moving the sleeve in the barrel.

Here are the main steps for tramming in train:

1. Set the mount parallax indicator (if any) at zero. Train the gun until the train-angle indicator shows that the mount is at the approximate train angle for tramming. The value of the angle is entered in the battery log.
2. Uncover the tram blocks for tramming in train, and seat the ends of the tram firmly in the rods of the blocks. Train the mount if necessary to do this.
3. With the tram ends seated, train the mount carefully in MANUAL to compress the tram until the marks on barrel and plunger line up exactly.
4. Take a reading on the train-angle indicator dial. It should agree exactly with the value given in step 1 above. If not, the indicator should be adjusted until it does.

The tramming operation in elevation is similar to that for train, except that the mount must first be trained to a point at which roller path compensation is zero. (This is 90° from the roller path high point.) This train angle is recorded in the fire control log, or can be read on the roller path compensator dial. Use the elevation tram blocks and elevation angle dial. The same tram is used in elevation and train.

BENCH MARK CHECKING

Director sight alignment is in principle analogous to gun mount boresighting and sight alignment, and bench mark checking of a director is equivalent to gun mount tramming. It is important that the director be bench-mark checked before any guns are aligned with it. A bench mark is an engraved metal plate secured to a fixed point on the ship's structure (e.g., the deck or a fixed bulkhead on the superstructure). When the director is cranked to a prescribed position in elevation and train, the director pointer, looking through his telescope, should see the reticle's crosshairs coincide with the bench mark's engraved target diagram. This is the principle of the use of the bench mark. In practice, the basic procedure is approximately as follows:

1. If the director uses parallax corrections, set these at zero.
2. If the director uses inputs of level and crosslevel, set these at zero.
3. Obtain the bench mark reading from the ship's records.
4. Move the director until the crosshairs of the pointer's telescope are on the bench mark.
5. The train and elevation dials should now read the previously recorded bench mark values. If they do not, the dials must be adjusted until they do agree with the bench mark values, with the crosshairs still on the bench mark.

Because of flexing of the ship's structure while afloat, small periodic errors may develop which cause corresponding discrepancies in bench mark observations. So long as they do not increase systematically in one direction, and so long as they remain small (on the order of 2 to 3 minutes), the weapons officer may choose to ignore them. Whenever a ship is bumped

while mooring or weathers a bad storm at sea, it is a good idea to check bench mark values at the first opportunity.

DIRECTOR OPTICS AND RADAR ANTENNA ALIGNMENT

Present types of gun fire control directors range from small lead-computing types with but one lead-computing sight and no radar to directors with two telescopes, slewing or battery officer's sight, stereoscopic rangefinder, and radar antenna. The details of sight alignment procedures vary from one mark and mod to another, but the principles for all of them are similar, and resemble those brought out in connection with gun mount boresighting. As they apply to fire control directors, these principles can be summarized as follows:

1. One line of sight (in the Mk 37 director, for example, that of the pointer's telescope) is used as a reference for train, elevation, or both. All other lines (in Mk 37 the train telescope line of sight, the rangefinder line of sight, the slewing sight line of sight, and the radar antenna axis) are adjusted to it. The reference line has originally been adjusted on the director bench mark. (See the previous article.)
2. All ballistic corrections are reduced to zero, parallax correction is set at zero, and level and crosslevel are locked at zero.
3. A suitable target is selected at a minimum range of several thousand yards (the exact value is prescribed in the applicable type commander's instructions), and the director is trained and elevated until the reference line of sight is aligned with the target. The other lines are then adjusted so that all are on the same target. An astronomical body is suitable for this operation so far as optical lines of sight are concerned, but not for radar.
4. The radar antenna axis is aligned with the other lines on a distant visible nonastronomical target (helicopter or radar reflector mounted on a motor whale boat) that gives a clear response on the radar tube and provides optically and on radar a good point for alignment. The procedure is first to put the director precisely on target optically, and then to adjust antenna alignment to give optimum "on target" indication in the radarscopes.
5. Dials and synchro transmitters may be aligned at a suitable point in the procedure. All dials should agree with the dial on the reference line of sight instrument (e.g., in Mk 37 directors this would be the pointer's dial). All synchros should be zeroed to the corresponding dials, in a separate operation.

SYNCHRO ZEROING

Most fire control directors transmit their outputs to other units in the system by means of a-c synchro transmission. The synchro-zeroing phase of internal alignment is designed to ensure that when a given dial or pair of dials read zero, the corresponding synchro transmitters are producing the zero-position voltage pattern. The procedure for verifying the transmitter zero position is to let its output drive a synchro receiver to approximate zero position, then use a sensitive a-c voltmeter to make the fine adjustment. Where synchro transmitters are paired in double speed, each synchro must be zero-checked separately. Because bias voltages from sources outside the synchros are used in some double-speed systems, the zero-checking should be done directly from the synchro terminals, not from terminal boards or other points in the circuit.

Other types of synchros are zeroed by using modifications of this fundamental procedure. For details of all synchro zeroing and other adjustment operations, see MIL HDBK 225 (AS), which supersedes OP 1303.

ALIGNMENT IN DRYDOCK

So far as battery alignment is concerned, the Weapons officer is concerned principally with alignment afloat, rather than with alignment in drydock, which ordinarily occurs only at intervals of two years or more. For this reason, the description of drydock battery alignment operations is presented briefly and without full details. For details, see OP 762 and weapons detailed instructions issued by the Naval Ordnance Systems Command and Type Commanders.

ORIGINAL ALIGNMENT IN DRYDOCK

The original alignment of ordnance installations is made in drydock. Battery realignment in drydock usually takes place during regular overhaul periods thereafter.

Its two principal phases are alignment in train and alignment in elevation. In the following discussion it is assumed that all elements of the system already have been properly installed and are functioning properly, and that these elements are mechanically aligned within themselves.

Alignment in Train

The purpose of battery alignment in train is to adjust the battery so that when the dials are matched and no ballistics or horizontal parallax is introduced, the lines of sight of directors and guns, and the axes of the bores of the guns, are all parallel in train at any angle of train.

The first step in actual alignment in train is to establish a centerline from which to measure horizontal angles. In most cases, because of the interference of the ship's structure, this line will take the form of an "off-set centerline" ashore, parallel to the real centerline of the ship. The centerline is established by use of surveyor's transits.

Next step is to establish the center of rotation of each trainable element (such as gun mounts and directors), so that a transit may be set up to measure the true angle of train of the element. After it has been plotted, the center of rotation must be checked when the element is trained. When verified, the center of rotation is permanently engraved so that it can be used in the future checks. On enclosed mounts, the mark is on top of the shield.

It is now necessary to establish zero train—that is, to set the train dials of each element so that when the dials read zero train, the line of sight or bore axis of each element is parallel to the centerline of the ship, and pointing forward. (On the after elements the dials are set at 180°, with elements pointing aft and parallel to the centerline.

With zero train established and the dials set, permanent reference marks must be established. A bench mark and angular reading for each director and a tram reading for each mount or turret are established. At any future time when it is necessary to verify dial accuracy, each element can be trained onto its reference and the dial readings checked, as described earlier in this chapter.

Alignment in Elevation

After battery alignment in train comes alignment in elevation. The purpose of alignment in elevation is to adjust the battery so that at any angle of train, and at any angle of elevation, the lines of sight of directors, the lines of sight of gunsights, and the axes of the bores of guns, will all be elevated by exactly the same angle above a common reference plane. (Again, we assume no vertical parallax or ballistic correction, and that dials match.)

The reference plane chosen is an actual plane on the ship; that is, it is the plane of the roller path (main horizontal bearing) of one of the elements of the battery. Ideally, the plane chosen must have the smallest possible inclination between it and the roller paths of the other elements of battery. The choice of this plane will vary, depending upon the type of ship. Because AA or dual-purpose battery directors can control more than one battery, one standard reference plane for all batteries is necessary.

Elevation alignment is principally concerned with one primary factor —the tilt or inclination of roller paths. The effect of the roller path tilt or inclination on elevation, if not corrected, is shown, greatly exaggerated, in figure 8-4. Each of the two gun mounts in the figure is elevated to the same angle (A) with respect to its roller path, but the angle of each (B and B') with respect to any common reference is not the same.

The principal operation in elevation alignment in drydock is the procurement and interpretation of roller path data. Roller path data are actually a series of readings showing the inclination of a trainable element (usually a gun mount or director) at points all around the roller path, relative to some fixed plane. In drydock this is usually a horizontal plane established by a level. The relationship between any roller path and the horizontal is defined by the amount of tilt at the highest point of the path, and the relative bearing of this point. Figure 8-5 shows this diagrammatically.

These data are determined by measuring roller path inclination at regular angular intervals through the full arc of train possible with the mount or director, tabulating them, and plotting them on coordinate paper. The general procedure for plotting and interpretation of the data resembles the afloat system alignment procedure described later in this chapter.

The instrument most commonly used for elevation alignment procedures in drydock is the gunner's quadrant. This instrument, which is illustrated in figure 8-6, is a high-precision device designed to measure the angle of inclination of a flat surface with respect to the true horizontal. (The true horizontal is defined as a plane tangent to the earth's surface at the point of measurement.) Two types are in common use; figure 8-6 shows the Mk 3 Mod 1, which is characterized by a vernier scale to give maximum accuracy. The instrument consists of a base, the bottom of which is ground to an accurate plane surface, an arc mounted perpendicularly on the base, an arm containing a spirit

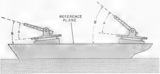

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Figure 8-4.—Effect of roller-path inclination on elevation.

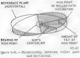

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Figure 8-5.—Relationship between roller path and horizontal.

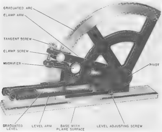
level, and a clamp arm. The level and clamp arms are pivoted. The clamp screw can secure the level arm at any desired position on the arc. The clamp arm is connected to the level arm by a tangent screw for making fine adjustments. The level in the level arm is a slightly curved graduated glass tube filled with colored alcohol and containing an air bubble. The level arm also carries the vernier scale, which slides along the arc, and a magnifier glass.

In use, the instrument is placed with its flat base on the surface whose inclination is to be measured (the slide of a gun, for example), with the quadrant pivot toward the center of rotation, and the level and clamp arms are adjusted until the level bubble is centered in its graduations. Small adjustments can be made with the tangent screw, and the inclination is read with great precision from the graduated arc and vernier.

The other type of gunner's quadrant (not shown) is the Mk 7 drum type. It operates in a manner similar to the Mk 3, but is not as accurate.

In gun mounts and turrets, compensators correct for roller path tilt by adding a compensating tilt algebraically, depending on mount train angle. The amount of the correction is at each point in train equal to the amount of tilt, but opposite in direction. Figure 8-7 shows the dial of a type of roller path compensator used in many 3" mounts. The "B" scale is driven by the training gear and shows the angle (0° is displayed in the figure) between the present position of the mount and the high point of the roller path. The "A" scale index pin, which is set by maintenance personnel, shows the amount of tilt tabulated or plotted for the high point of the roller path. This automatically introduces the proper elevation correction at every train angle. Index "C" shows mount train position (180° is displayed in the figure).

In ships with more than one director, most of the directors are normally equipped with



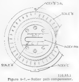
53.121
Figure 8-6.—Gunner's quadrant Mk 3 Mod 1 (vernier scale type).

roller-path compensators which in principle function as described above.

After the reference plane of the battery has been established, the next step is to align the stable vertical or stable element so that the plane of its roller path is exactly parallel to the reference plane. This is necessary because the stable element measures continuously the tilt of its roller path (which represents the reference plane) with respect to its gyrostabilized parts. Since this correction is applied to gun elevation, the stable element's roller path must be parallel to the reference plane, so that its tilt at any instant will be the same as those of the director and the gun mounts.

No roller path tilt corrector is provided for the stable element. Stable element correction is introduced by shimming the roller path until it is parallel with the selected reference plane.

This is a precision operation which requires (1) measurement of tilt with a gunner's quadrant, (2) tabulation and plotting of the tilt data, (3) calculation of the required thickness of the shims to be inserted under the roller path, (4) fabrication, machining, and installation of the shims, and (5) recheck through the full angle of train with the gunner's quadrant. Figure 8-8 shows a stable element with gunner's quadrant installed for checking alignment.



110.53.1
Figure 6-7.—Roller path compensator.

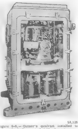
BATTERY ALIGNMENT AFLOAT

Since a ship is not a rigid structure, upon loading and putting to sea the space relationships between elements of a battery change, and correction for these changes must be made. The process involved is known as battery alignment afloat, and must be carried out while the ship is waterborne, by different procedures than those used for the original alignment in drydock.

Before initiating the actual alignment procedures, ensure that all elements are functioning correctly and that all transmission systems are properly adjusted. Have a routine transmission check carried out just prior to the alignment check. (For more detailed procedures refer to OP 2456, Volumes 1 through 5.)

TRANSMISSION CHECK

Before proceeding with the alignment it is desirable to check the synchro transmission system to assure (1) that the transmitters are sending out a correct electrical signal for a given mechanical input, and (2) that the receivers are accurately converting this electrical signal into a mechanical or electrical signal equal to that of the transmitters. It is first necessary to set the synchros to electrical zero. Any of several methods may be used, and each synchro dial



53.128
Figure 6-8.—Gunner's quadrant installed to check alignment of stable element.

should read zero when that synchro is on electrical zero. The next step is to check transmission, which is accomplished as follows:

1. Man the telephones at the stations to be tested.
2. Set the fire control switchboard to transmit from:
    a. The directors to plot.
    b. Plot to the gun mounts.
    c. The directors to the guns directly (bypassing the rangekeeper or computer, where possible).
    d. The stable element to the directors (to transmit level and crosslevel).

3. Turn each transmitter to various readings (usually in 10° increments) throughout its operating range and compare the received readings with the transmitted values. They should check exactly. Any errors of position, direction, or firmness of position should be investigated by standard synchro methods. Particular attention should be paid to the action of the receiver dials when coming to rest. They should stop quickly and evenly in agreement, and there should be neither sluggishness nor long oscillation.

PURPOSE OF TRAIN AND ELEVATION ALIGNMENT

Train alignment afloat is accomplished to ensure that, with zero settings of sight deflection and parallax, the director and gun lines of sight and the gun bore axes are parallel (in the horizontal plane) when the director and gun are matched at any point in train.

Since it is impractical to use multiple targets, train alignment is checked on a single target with parallax correction. When the gun dial pointers are matched, proper parallax set in, and zero settings of sight angle and sight deflection set in at the guns, the director and gun lines of sight and the gun bore axes will—if the system is properly aligned—converge on any given target, at any range, and on any bearing.

To accomplish this check, it is necessary to introduce parallax both into director train (in multiple director installations) and into gun train. It is therefore necessary to check the parallax system before beginning the actual alignment. Proper correction of parallax errors is important where there are a number of directors and large horizontal distances between units. Hence, all parallax correctors on guns and directors should be checked for:

1. Correct amount of parallax at various bearings and ranges.
2. Correct direction of applied parallax correction.

The purpose of afloat alignment in elevation is identical to that of elevation alignment in drydock. This objective is attained by selecting some plane as the reference plane of the battery, so that the elevation of all units, when measured from that plane or a plane parallel to it, is equal. Again, a single target (the horizon in this case) is used for the check.

SYSTEM ALIGNMENT IN TRAIN (TRAIN CHECK AFLOAT)

After a bench-mark check has been run on the director, it is then possible to proceed with actual alignment of the various battery elements. Preferably, this should be done with the ship at anchor in smooth water. If the battery has never been aligned afloat, a complete train check must be made; otherwise, a preliminary test may be made to determine if a complete check is necessary. The preliminary test is conducted as follows:

1. Establish telephone communication between director and guns.
2. Set the switchboard for normal operation—i.e., director to plotting room, which in turn transmits to the guns.
3. At the computer or rangekeeper, have time motor off and power switch on.
4. Set sight angle on 2,000 minutes and sight deflection on 500 mils (their zero values) on their respective computer counters.
5. Set and lock level and crosslevel at zero.
6. At the guns, set sight angle and sight deflection to their zero values; put the guns in local, hand, or manual control.
7. Select a distant target off one beam. Train the director until the vertical wire is just off the target, so that motion of the ship will carry the wire across the target.
8. Obtain the range to the target by the most accurate means available, and set the parallax correctors to give the proper correction for this range.
9. Match pointers at the guns.
10. As the director line of sight swings on target, the director trainer calls (phone) "mark" to the gun trainer. This is continued, the gun trainer meanwhile moving the gun, from one direction, until both gun and director telescopes are on the target at the same instant. The amount of displacement between the follow-the-pointer dials at the gun is the amount of error and should be recorded. This process is repeated, with the gun trainer bringing his vertical wire on target from the opposite direction, and the error recorded. The algebraic difference between the two errors is the lost motion of the gun. The mean of the two errors is the gun error. The example in table 5-1 illustrates how this is done. Assume that the process is repeated three times. The gun trainer notes the following readings on the call "mark" as he trains his gun onto the target alternately from left and

Table 8-1.—Gun error and lost motion error

(1) Approaching from the left	(2) Algebraic difference from director	(3) Approaching from the right	(4) Algebraic difference from director	(5) Absolute difference (between column (1) and (3) regardless of sign)
1. 010°58' - - - - - -	-2	011°02'	+2	4
2. 010°59' - - - - - -	-1	011°03'	+3	4
3. 010°59' - - - - - -	-1	011°03'	+3	4
Total - - - -	-4	- - - - - -	+8	12

110.140

right; the director calls "mark" on target at his train dial reading of 011°00' each time.

The total absolute difference (regardless of sign) in the three sets of readings (total of column (5) figures) is 12; dividing this by the number of observations (3) yields the mean lost motion; 4 minutes. Columns (2) and (4) show the difference in each reading between the director's train dial indication and the gun mounts train dial indication at the instant of the call "mark" (when the director train dial read 11°00'). These values bear algebraic signs. The column (2) total is -4; the column (4) total is +8; the algebraic sum is therefore +4. Dividing this by 3 to get the average, we have the value +1.33' (rounded). This is the gun train dial mean instrument error; it indicates that, disregarding lost motion, the gun train dial tends to read on the average 1.33 minutes higher than the director train dial (for the same target) without ballistic or parallax corrections.

The principle described here applies wherever multiple readings are used to determine instrument errors and lost motion.

11. Repeat the process, using a target on the other beam if practicable, and in any case a target at a widely different train angle from the first, and record the gun error and lost motion.

The gun errors should be equal and small. If they are equal and large (2 or 3 minutes larger than the lost motion), it is an indication that a constant error exists, and that this error may be corrected by adjusting the train response. In so doing, the dial which shows the actual train of the element (not the dial on the synchro receiver) must be moved. If the errors are not equal, a complete train check is necessary.

The complete train check is exactly like the test described above, except that a series of targets is used, at 10° or 15° intervals if possible.

The complete train check will furnish gun errors which, when plotted with their bearings as abscissas, should show a slightly ragged scattering of points. A line parallel to the abscissa which passes through the mean of these points (i.e., with approximately equal deviations above and below the line) can be considered as the zero error line. Its distance above the abscissa will be the constant error of the system, which can be removed by adjusting the response. If a sine curve results, it indicates errors such as improper parallax settings. If the points are erratic with large deviations from the zero line, it indicates damage to the dial drive shaft, such as a sheared coupling or slipping gears.

SYSTEM ALIGNMENT IN ELEVATION (HORIZON CHECK)

To adjust the battery to its reference plane, it is necessary to compile data on the relative positions of all guns with respect to the reference plane as represented by the line of sight of the reference director. This is done by means

of a horizon check, which compares the elevation angles on the dials of director and guns when all are laid successively on a series of points completely around the horizon. If we compare director elevation and gun elevation at a common point (horizon), after accounting for any known angular divergencies between the two units, such as that caused by the vertical distance between guns and director and the angle of the gun sights with respect to the bore axis (sight angle), their elevations should be equal.

Figure 8-9 shows the essential geometry of this operation. For the moment assume that there is no uncorrected inclination of the gun mount roller path, and that the reference plane is horizontal. The line of sight from the director telescope (which is a little more than 100 ft above the ship's waterline) to the horizon is AB; the line of sight from the gunsight telescope (about 17 ft above the waterline) is CB. Both lines of sight are depressed below the horizontal; the higher you are above the water, the greater the depression angle or dip will be. (Bowditch's American Practical Navigator has a table of dip values and range to the horizon for many values of height above the water surface.) Figure 8-9 shows a dip of -10' for line of sight AB and a dip of -4' for CB. The dip difference is -6'.

To simplify mechanics of tabulation and calculation, the gun is customarily elevated by an arbitrary elevation angle (in this case, 20°) in performing the horizon check. Since the gunsight telescope is depressed 4' below the horizontal because it is pointed at the horizon, the value of sight angle is actually 24' (the sum of gun elevation and gunsight dip).

On the gun mount dials, zero gun elevation (gun parallel to reference plane) is arbitrarily

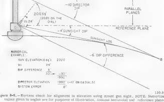


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Figure 8-9.—Horizon check for alignment in elevation using mount gun sight. NOTE: Numerical values given to angles are for purposes of illustration. Assume horizontal and reference planes coincide.

called, as you already know, 2,000'. The director line of sight (LOS) is dipped -10' when pointed at the horizon. If roller path tilt is correctly compensated in the gun mount (and in the director if the director has a compensator), then, after applying an algebraic correction equal to the sum of dip difference and arbitrary sight angle, gun elevation should equal director elevation. (The gun elevation value corresponding to -10' director elevation is, of course, 1990'.)

In figure 8-9, if we subtract sight angle (Vs) and dip difference from gun elevation (Edg'), we arrive at line CD of the diagram (see numerical example as well). If CD is parallel to AB, the gun and director are elevated at equal angles above (or below) the reference plane, are aligned in elevation, and there is no system error. Or,

Edg'-(Vs - dip diff.)= director elevation (Ed).

Now, by rearranging these quantities slightly, to:

Vs - dip diff. = Ed - Edg'

we can obtain an array of values that provides for checking with minimum time and effort. We simply subtract gun elevation from director elevation (values read at each different angle of train; and the results should equal sight angle plus dip difference (values that are set and remain constant throughout the check).

Steps in performing a horizon check are as follows:

1. Choose a day when the ship has little roll and the horizon is clearly defined.

2. Man stations and phones.

3. Make sure that the synchro transmission system has been checked recently, and that the director has been checked on its bench mark.

4. If possible, use the reference director, which has no roller-path inclination compensator.

5. Record the roller-path inclination compensator setting on the gun concerned. It should agree with the value determined during the last system alignment check in elevation.

6. Look up the height of gun and director, and compute the dip in the horizon for each. From this information you can compute the dip correction for each gun, by subtracting the dip angle for the gun from that for the director.

7. Set the dials of the computer or rangekeeper so that no corrections in elevation are introduced by its mechanism.

8. If the test is to be performed with the boresight telescope, install it. If the gun sights are to be used (the normal procedure), they must have been boresighted recently. Set a positive value of sight angle at the gun and record this setting. The purpose of setting in this sight angle is to ensure that the elevation reading of the gun will be higher than that of the director at all bearings.

9. Train the director to a given bearing; elevate or depress the director line of sight so that it will move across the horizon as the ship rolls. Record for later reference the value of director elevation used on each bearing.

10. Train the gun to the same bearing as the director.

11. The gun pointer depresses his gun until it is approximately on the horizon. When the director sight crosses the horizon, the director pointer calls "mark," and the gun pointer turns his handwheels until his line of sight crosses the horizon simultaneously. When he is on, he checks back to the director exactly on the mark, so that when either one calls "mark" the other will be exactly on the horizon. To eliminate lost motion, always move the director and gun lines of sight onto the horizon from the same direction.

12. When the gun is on, read and record both the mechanical and the follow-the-pointer dials. The follow-the-pointer dials will read the total uncorrected gun error, which should equal the difference between the director elevation and the gun elevation as read from the mechanical dials.

13. Repeat the foregoing process at 10° or 15° intervals throughout the training arc of the gun.

14. Obtain the uncorrected gun error by subtracting the director elevation from the gun reading (never the reverse), and record the result for each bearing.

A sample of data obtained in this way follows:

Bearing	Gun	Director	Difference (uncorrected gun error)
0°	1990	1976	14
15°	1991	1979	12
30°	1993	1982	*11
45°	1993	1981	12
60°	1991	1978	13
75°	1990	1974	16
90°	1988	1968	20
105°	1987	1963	24
120°	1988	1960	28
135°	1990	1958	32
150°	1988	1951	37
165°	1990	1950	40
180°	1992	1950	42
195°	1990	1946	44
210°	1991	1946	**45
225°	1992	1948	44
240°	1991	1948	43
255°	1995	1955	40
270°	1994	1957	37
285°	1995	1963	32
300°	1993	1965	28
315°	1990	1966	24
330°	1987	1968	19
345°	1988	1972	16
360°	1990	1976	14

*High point.
**Low point.

The data tabulated above are plotted by the method shown in figure 8-10. Note that the difference between gun elevation and director elevation varies with different angles of train. If the roller path compensator had been properly set (no uncorrected inclination), these differences would have been constant and the data would plot as a straight line. As it is, however, the differences vary, indicating uncorrected inclination, and the data will therefore plot as a sine curve. The example shown here is for the full 360° arc of train, which is a condition almost never realized in practice. Hence, while both a high point and a low point are shown on our sample curve, only one of these points may be present on the curves obtained in an actual installation.

After plotting and drawing the curve, find the zero axis (i.e., the curve's axis of symmetry, which is parallel to the abscissa or x-axis). Either of two methods may be used:

1. If both the high point and the low point have been plotted, add the high point and low point values, and divide by 2. The resulting value is the ordinate (y-axis value) through which the zero axis passes. Plot this either on the y-axis or on the curve, and draw a line through it parallel to the abscissa. You have now drawn the curve's zero axis.

2. The alternate method, which is usable if either the high or low point has been plotted, is to take a point on the sine curve 90° from the high point or the low point, and draw through it a line parallel to the abscissa.

The distance of the zero axis above the abscissa represents the error due to all causes other than roller-path inclination. Figure 8-10 shows how this error is broken up into component parts. Sight angle and dip correction are known values; the remaining error represents the system error. This constant system error can be removed by adjustment of the elevation response at the gun. When this is done, tram values in elevation will have to be corrected.

The low point of the curve represents the bearing and inclination of the high point of the gun roller path, with respect to the reference plane (in this case, the director roller path). If no low point is shown on the plotted curve, it may easily be calculated, since it would occur at a bearing 180° from the high point of the curve. Further, it would occur at the same distance from the zero axis of the curve as did the high point. The bearing of the low point of the curve represents the bearing of the high point of the gun roller path. The distance of the low point below the zero axis of the curve represents the inclination of the gun roller path. In the example shown in figure 8-10, the high point of the gun roller path (represented by the low point of the sine curve) is at 30° train, and the inclination at that point is 17 minutes. Thus, for this example, the following desired data are available:

Bearing of high point. . . . 30 degrees
Inclination of high point . . 17 minutes
Constant error of system . 6 minutes

Note that the low point of the sine curve is the high point of the gun's roller path. We know

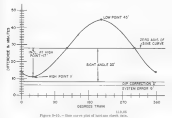

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Figure 8-10.—Sine curve plot of horizon check data.

that the uncompensated roller path inclination plots as a sine curve. When the gun is trained to the highest point on its roller path, the actual gun elevation to the horizon will be at its lowest value with respect to the reference plane. This occurs because the gun's roller path has not been completely corrected to the reference plane. In other words, the high point of the gun's roller path has raised the gun above the reference plane, and to elevate to a given target now requires less elevation angle between the gun bore axis and the gun roller path. With gun elevation at its lowest value, the difference between gun and director elevation will be a minimum; a minimum difference is the low point of the sine curve.

CALCULATING CORRECT COMPENSATOR SETTING

The horizon check is usually made with some setting already on the roller-path tilt compensator. The tilt found by the check, therefore, is not the total inclination but only the uncorrected inclination. It is an additional inclination to that for which the compensator has been set. This newly discovered inclination must be added vectorially to the inclination previously known to exist, in order to determine the total inclination for which the compensator must be set. This may be done graphically, as shown in figure 8-11. In this figure the results obtained previously were used to illustrate the method, which is as follows:

1. The line OA is drawn to represent zero train.

2. The original setting of the compensator (8.5' at 150°) is plotted as line AC. This is done by measuring off the angle clockwise from OA, and measuring the inclination on that line to a convenient scale.

3. The inclination found (17') is plotted as AB on bearing 30 degrees.

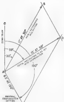

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Figure 8-11.—Compensator-setting calculation.

4. CD is drawn parallel to AB, and BD is drawn parallel to AC. These lines intersect at D.

5. A line AD is drawn from the origin to D. This line represents the total inclination. Its bearing (59°) and length (15') may be read according to the previously established scale. These are the data that must be set into the compensator.

It should be noted that compensators are constructed to read the error rather than the correction. Thus, if the error is 15' at 59°, the bearing scale is turned to 59°. Then the inclination of 15' is set on the inclination scale, and the adjustment is completed.

SIMPLE ELEVATION CHECK

When at sea, it is desirable to perform a simple elevation check at frequent intervals. The method is the same as that in the horizon check, except that each gun is checked at only one point on the horizon. The difference between gun and director reading after correction for sight angle should equal the dip correction. If it does not, an error of some sort is present and must be investigated. Before undertaking a complete horizon check as a result of such disagreement, however, check to see that the transmission system is functioning properly, and that the roller-path tilt compensator is at its proper setting, both for bearing and for inclination.

CHECK OF AUTOMATIC FOLLOWUP SYSTEM

After a battery has been aligned in elevation, a test of the automatic followup system should be made. This involves training on a target, setting up the problem in the computer and positioning the gun in automatic (using computed gun orders), setting the sights according to generated sight angle and sight deflection, and checking to see whether the gun telescopes are on target. If they are not on target, the amount that sight angle and sight deflection must be changed from the computed values to bring the sights on target represents the error of the system. To eliminate trunnion tilt errors when this test is made, it should be done when there is little or no roll.

The preceding discussion of battery alignment has dealt only with gun batteries. Proper alignment is equally important in any other director-controlled battery such as torpedo, missile launcher, etc.; but the methods used will vary with the characteristics of the battery to be aligned.

FIRING CUTOUT MECHANISMS

In terms of the definition of battery alignment at the beginning of this chapter, the battery is aligned when, with the dials matched and parallax on zero, all the lines of sight and the axes of all gun bores are parallel, regardless of the ordered angles of gun train and gun elevation. In practice, however, the battery check is not complete until: (1) the firing cutout cams in each gun have been plotted, cut, and installed; and (2) the firing cutout mechanisms have been checked, with the cams installed, to ensure that both the mechanical and the electrical firing circuits are interrupted properly whenever the guns move from a zone of safe fire to a danger zone.

Firing cutout mechanisms are designed to interrupt the mechanical and electrical firing circuits whenever the guns are trained or

elevated to a position where firing the guns would endanger ship's personnel or damage the ship. They should not be confused with the frameworks of steel tubing or depression-stop cams that are used to limit the movement of some light machine guns to safe zones of fire. Firing cutout mechanisms do not interfere with the free movement of the gun; this is done by the train and elevation limit stops.

The Naval Ordnance Systems Command (NavOrd) has issued strict, mandatory instructions—summarized in the next section—for the guidance of personnel responsible for plotting, cutting, installing, and checking firing cutout cams and mechanisms. In addition, special instructions not detailed here govern particular gun installations.

The importance of firing cutout mechanism layout, adjustment, and maintenance is difficult to overemphasize. Many casualties in which a ship's guns have fired into her own structure have been traced to the neglect of firing cutout mechanisms, or they have resulted from somebody's deliberate bypassing of these mechanisms. Every one of these casualties could have been prevented if the firing cutout mechanism had functioned properly. As was pointed out in the first chapter of this text, safety is a universal objective in all procedures relating to ordnance and gunnery. That is why firing cutout mechanisms must function effectively in all mounts and turrets in which they are installed.

NAVORD REGULATIONS FOR FIRING CUTOUT CAMS

Firing cutout mechanisms are designed to prevent firing into permanent parts of the ship's structure. In plotting the firing cutout cam, all removable parts of the ship's structure such as stanchions, handrails, lifelines, chests, and lockers are disregarded. Such movable equipment as boats, cranes, booms, davits, and hatches are secured in such a manner as to obstruct the line of fire as little as possible. The firing cutout cam is plotted around this secured position of the equipment.

Personnel, such as other gun crews and lookouts, that are stationed within the possible line of fire must be protected by the cutout cam; however such personnel are not normally protected against blast danger. In order that the firing cutout cam may be designed for the maximum possible zone, NavOrd does not approve of cutting cams to protect forestays, halyards, radio antennas, and such top hamper. Peacetime target practice must be arranged so as to keep the firing clear of these obstructions. In wartime, such hazards must be accepted.

The minimum clearance to be maintained between the extension of the axis of the gun bore and the fixed structure of the ship varies with different size guns. One reason for this is the lag between the time the cutout mechanism functions and the time the guns actually cease firing. For protection of the other installations, the minimum clearance is computed with the other guns and directors at zero degrees elevation and the angle of train at which they are normally secured.

Missile launchers for Terrier, Tartar, and Talos missiles are equipped with firing cutout devices of the type normally used in gun mounts. Terrier and Tartar launchers have an automatic blind zone cutout system incorporated in the missile launcher power drive to prevent pointing a loaded launcher within the nonfiring zones as determined by the ship's structure. Talos launchers also have a blind zone cutout system, similar to that on Terrier launchers, to prevent physical interference of missiles on the launcher with the ship's structure, but not to prevent pointing missiles at the ships's structure. Firing into the ship's structure is prevented by firing cutout devices, as on gun mounts.

TURRET DANGER-ZONE CUTOUT MECHANISM (CAM)

Although danger-zone cutout mechanisms vary in construction between different kinds of turrets, they all serve the same purpose—interrupt the firing circuit if a gun enters a danger or non-firing zone. In a representative 8-inch gun turret, this mechanism functions in response to the train and elevation drives. The train drive rotates a spur gear to which a cam is attached. High points on the cam represent non-firing zones. The elevation drive moves a rack carrying a plunger that touches the cam. When the gun enters a non-firing zone, the plunger rides up on a high point and actuates a rocker arm which is connected—by means of a linkage—to two switches. This action opens one switch, breaking the firing circuit. The other switch closes a circuit to a red-light indicator system, indicating that the gun is in a danger or non-firing zone; at the same time, it opens a circuit to a green light. The green light indicates a safe or firing zone; it lights when the gun moves out of the danger zone and normal firing is restored.

On large caliber guns only the electrical firing circuit is interrupted by the cutout mechanism. The percussion firing circuit is not affected by the cams.

The proper settings for firing cutout mechanisms are outlined in the applicable OPs. Usually the OPs will list the settings for the individual turrets in ships of a class. After the cams are installed, they must be checked by the methods similar to those outlined for smaller guns.

MOUNT FIRING CUTOUT MECHANISMS

All mounts of 5-inch caliber and smaller incorporate mechanisms wherein one cam, referred to as a profile cam, controls the firing circuit when the gun is in or near a danger zone of fire in either train or elevation. The mechanical action of these mechanisms differs slightly from gun to gun, but in principle they are the same and can be considered collectively.

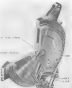
The cutout feature of profile-cam firing cutout mechanism is accomplished by the action of a plunger or cam follower on the face of a disc-shaped profile cam. When the plunger rides up on a high point of the cam, which represents a danger or nonfiring zone, it pushes against the plunger lever, which in turn causes sufficient movement of another lever or levers to interpose a break in the firing circuit. In most guns, this movement interrupts both the electrical and the percussion firing circuits.

Figure 8-12 shows a cutaway view of a typical firing cutout mechanism plunger and profile cam; this one is from a 5"/54 mount. The cam is turned by gun train order at one-to-one speed, while the plunger mechanism moves radially from near the center to the edge of the cam in accordance with gun elevation order. A point near the center of the cam represents maximum gun elevation, and the outer edge minimum gun elevation.

The rise from cutaway area to the raised portion of the cam is a 30° incline. This permits the plunger cam follower to ride from the low surface of the completed cam to the high surface without excessive wear or scoring. Cutout occurs when the plunger is two-thirds of the way up the incline. A switch opens the firing circuit, and a mechanical clutch disconnects the linkage to the firing mechanism from the firing pedal.

PLOTTING, CUTTING, AND INSTALLING THE CAM (PROFILE CAM MECHANISM)

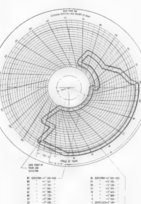
Since the contour of the cam determines where the gun can and cannot fire, it is obvious



53.131
Figure 8-12. —Cutaway view of firing cutout mechanism plunger and cam.

that the most critical step in firing cutout mechanism installation is concerned with plotting and cutting the cam's contour. By far the most important kind of firing cutout mechanism is the profile cam type; therefore the plotting and makeup of this type only will be discussed in this chapter.

The entire firing cutout mechanism, with the exception of the profile cam itself, is assembled and installed on the mount during manufacture. The profile of the cam depends on the obstructions presented from the point of view of its location after installation; hence the cam profile can be determined only after installation. It is necessary first to determine the safe firing zone, i.e., the locus of all gun positions in which firing may be safely performed in accordance with NavOrd standards. This zone must be plotted in such a way that it is immediately usable as a guide in shaping the cam itself. The plot is then transferred to the cam plate blank and cut into the blank. The last



53.132
Figure 8-13. — Simple cam plotting sheet.

step is installation of the cut cam and verification of its proper functioning. Here is the step-by-step procedure, in brief:

1. Install a borosight in the gun barrel, and sight through it to establish, for each successive 5° increment of train angle, the lowest (and, if applicable, the highest) elevation angle at which it is safe to fire, in accordance with NavOrd standards.

2. As these elevation and train angles are determined, they must be tabulated and plotted on a special polar-coordinate form illustrated in figure 8-13. Note that a different form is issued for each caliber, mark, and mod of gun, and even for the right- and left-hand guns in a twin mount (because their cams turn in opposite directions).

3. Transfer the plot to another copy of the plotting sheet to make a smooth copy. See the OP or OD on the gun for such information as minimum radius of curves, how wide the cam slope should be, etc. Verify the plot for accuracy.

4. Let the cam be cut in accordance with the verified plot. This is generally done by a navy yard machine shop, not by ship's personnel.

5. Install the cam and check it throughout all angles of train to verify that it complies with NavOrd standards. This can be done by positioning the gun with borosight in place as in step 1, and checking the functioning of the firing circuit and mechanical firing linkage, using a firing circuit test lamp to check the circuit and observing the functioning of the linkage.

For details on the procedure for any specific mark and mod of mount, see the OP or OD on the equipment.

CHAPTER 9

SPOTTING AND NAVAL GUNFIRE SUPPORT

INTRODUCTION; DEFINITIONS

Gunnery operations, rather than principles of weapons and associated equipment, are the principle subject of this chapter. In studying it, bear in mind that operational methods and techniques are broadly determined by the Chief of Naval Operations, and are published as doctrine in NWPs, NWIPs, and related publications, as described in chapter 1, and by other responsible command echelons. The following material is not intended to supplant such sources of doctrinal information.

This chapter takes up the problem of gunfire control where chapter 6 left off, and goes on to discuss certain advanced aspects of fire control in the special situation where naval guns are used against targets ashore, particularly in connection with amphibious attacks.

As chapter 6 stated, not all the factors that affect the flight of a projectile can be precisely evaluated in advance of firing. Even with the best fire control equipment available, experienced gun crews, and efficient fire control personnel, the opening shots may not hit the target. It is therefore necessary to apply corrections (spots) to the initial firing data to bring the shots on the target. The corrections are applied to gunlaying data for subsequent rounds fired. This technique is called spotting.

Before proceeding further, we will define some terms that relate to gunfire support and spotting. Those terms are as follows.

SLOW FIRE. In slow fire, firing is deliberately delayed to allow for application of spots or conservation of ammunition.

RAPID FIRE. In rapid fire, firing is NOT delayed to apply corrections.

SALVO. A salvo consists of one or more shots fired simultaneously by the same battery at the same target.

SLOW SALVO FIRE. In slow salvo fire, the guns are loaded on command and fired together at a fairly slow rate.

RAPID SALVO FIRE. In rapid salvo fire, the guns are loaded on command and fired together at a RAPID rate. (Both slow and rapid salvo fire are used to establish a hitting range to a surface or land target.)

RAPID CONTINUOUS FIRE. Rapid continuous fire is the fastest firing method for 5" guns. The pointer's firing key is locked in the closed position, and the rate of fire depends only on the loading speed.

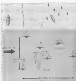
RAPID PARTIAL SALVO FIRE. Rapid partial salvo fire for a turret (6" and above) is synonymous with rapid continuous fire for a 5" gun. (Both of these types of fire will most often be used after the hitting range has been established or, in the case of the 5" gun, against aircraft.)

MPI. The Mean Point of Impact (MPI) is the geometric center of the points of impact of the various shots of a salvo, excluding wild shots (fig. 9-1).

DISPERSION. The dispersion of a shot is the distance of the point of impact of that shot from the MPI. Dispersion in range is measured parallel to the line of fire, and in deflection at right angles to the line of fire, in a horizontal plane. Dispersion in range is positive when the shot falls beyond the MPI. Dispersion in deflection is positive when the shot falls to the right of the MPI. The algebraic sum of the dispersions in range (or deflection) of the several shots of a salvo must equal zero. (See definition of MPI.)

APPARENT MEAN DISPERSION. The apparent mean dispersion of a salvo in range (or deflection) is the arithmetical average of the dispersion in range (or deflection) of the several shots of the salvo, excluding wild shots.

TRUE MEAN DISPERSION. The true mean dispersion is the arithmetical mean of the dispersions in range (or deflection) of an infinite number of shots, all assumed to have been fired under conditions as nearly the same as possible.



53.119
Figure 9-1.—Salvo pattern.

WILD SHOT. A wild shot is a shot with an abnormally large dispersion in range, or deflection, or both.

PATTERN. The pattern of a salvo is the area covered by the points of impact of the shots (except wild shots). The pattern in range is the distance measured parallel to the line of fire between the point of impact closest to the battery and the one farthest away, excluding wild shots. The pattern in deflection is the distance, measured at right angles to the line of fire, between the point of impact farthest to the right and the one farthest to the left, excluding wild shots.

HITTING SPACE. Hitting space (usually measured only in range) for a target is the distance behind the target (measured parallel to the line of fire) that a shot through the top of the target will strike the horizontal plane through the base of the target (fig. 9-2). It includes the projection of the target's vertical height upon the plane of the water plus the target's horizontal dimension in the line of fire (or depth). Hitting space in deflection is the angle subtended by the target.

DANGER SPACE. The danger space for a target is the distance in front of the target, measured parallel to the line of fire, that the target could be moved toward the firing point, so that a shot striking the base of the target in its original position would strike the top of the target in its new position (fig. 9-2). At most ranges, danger space is virtually equal to hitting space.

STRADDLE. A straddle is obtained from a salvo in range (or deflection) when, excluding wild shots, some of the shots of that salvo fall beyond, (or right and left, respectively, for deflection). The target in figure 9-1 A is straddled.

ERROR OF MPI. The error of the MPI is its distance from the target (fig. 9-1) or other reference point, such as the center of the hitting space, measured (in a horizontal plane) parallel to the line of fire for range and at right angles to the line of fire for deflection.

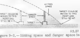
ELEMENTS OF SPOTTING

Now that you are familiar with some of the terms relating to spotting and gunfire support, we will discuss some of the problems encountered in these areas.

DISPERSION AND ITS CAUSES

The problem of spotting is complicated by dispersion. If a battery of guns is fired at the same instant with the same settings in range and deflection (this is salvo fire), the projectiles will not all land at the same point, but will be dispersed over the vicinity.

If the battery of guns were stationary and rigidly fixed in elevation and train, variations in range and deflection would be caused by (1) differences in weight and temperature among individual powder charges; (2) differences in



93.57
Figure 9-2.—Hitting space and danger space in range.

projectile weights; (3) variations in angles of projection (the longitudinal axes of projectiles diverge, in varying amounts, from the continuation of the bore axis as they leave the guns); (4) differences in projectile seating, causing variations in density of loading and initial velocity; (5) differences in erosion among the several guns, with corrections not precisely made. Such causes as these make a certain minimum amount of dispersion inevitable. There are other causes of dispersion which can be prevented. The motion of the ship may result in the pointers and trainers of guns being off target when the guns are fired. The same effect may result from failure to fire exactly simultaneously, causing different guns to fire at slightly different points in the roll.

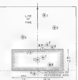
Director-controlled gunfire, although not subject to the same characteristic errors as pointer fire, is subject to its own characteristic errors. All such errors are considered accidental errors. They are revealed by analyses of firings, and their effects are governed by the laws of probability.

For discussion of the laws of probability in general the student is referred to any good text on the subject. Elementary discussions of probability will also be found in most textbooks on statistics. This chapter is primarily concerned with the practical aspects as applied to spotting of gunfire.

DETERMINING LOCATION OF MPI

The definitions discussed earlier will now be illustrated by an example (NOT necessarily typical) representing a salvo from ten 5"/38 caliber guns fired at range 8,500 yards against a target 40 feet high, 600 feet long, and with a beam of 90 feet. The target is situated with its length at 90° to the line of fire (fig. 9-3).

The danger space at this range, from column 7 of the range table (appendix 2, table A2-1), is 40/20 × 25 = 50 yards. Since the target "depth" is 90 feet, or 30 yards, the actual danger space is thus 50 + 30 = 80 yards. For most battle ranges the value of hitting space is the same as that for danger space. Hence hitting space is also 80 yards. Figure 9-3 represents the plan view of the target shown in terms of hitting space, an area 80 yards in range and 200 yards in deflection. The center of the hitting space is at C. (The fact that the target is not rectangular will be ignored.) The points of impact of the several shots are indicated by numbered dots and are identified by table 9-1, which gives the location of each impact from the reference axes, in this case taken as intersecting at the center of the target's waterline.



110.90

Figure 9-3. — Analysis of a salvo pattern.

The location of the MPI is determined by measuring the distance, in range and deflection, of the point of impact of each shot from convenient coordinate axes, and finding the mean of these distances. It is convenient to refer impacts to axes intersecting at the center of the target's waterline, as was done in the table. The mean of these distances is 80 yards over and 20 yards right, which locates the MPI 80 yards beyond and 20 yards right of the center of the waterline.

If we assume that the error of the MPI is its distance from the center of the hitting space, this is seen to be 40 yards over and 20 yards right.

DETERMINING APPARENT AND TRUE MEAN DISPERSION

In determining apparent mean dispersion, remember that it is the arithmetical mean of the dispersions of the several shots, without regard to sign. Once the MPI position has been plotted,

Table 9-1

Shot No.	Distance from reference axes			
	Range yd		Deflection yd	
	Over	Short	Right	Left
1	220		30	
2	170		70	
3	130			60
4	100		40	
5	90		60	
6	70			30
7	60		20	
8	20		50	
9		10		10
10		40	30	
Sum	850	50	300	100
	50		100	
Dif	800		200	
Mean	80		20	

110.57

the several points of impact are now referred to the MPI to determine individual dispersions and apparent mean dispersion, as shown in table 9-2.

Apparent mean dispersion, based on 10 shots, is, according to table 9-2, 62 yards in range and 32 yards in deflection. Based on such a limited number of observations, it is unlikely to be a true measure of accuracy of fire. The true measure of accuracy is the mean dispersion of an infinite number of shots, all fired under the same conditions. This is the true mean dispersion. It is obviously impossible to measure this value experimentally by firing an infinite number of shots, but a theoretical value can be found in the relation

$$D = D' \sqrt{\frac{n}{n-1}}$$

in which D is the true mean dispersion, D' the apparent mean dispersion, and n the number of shots from which D' was obtained. Table 9-3 gives the values of the ratio of D to D', i.e., values of

$\sqrt{\frac{n}{n-1}}$ for salvos of from 2 to 12 shots.

The true mean dispersion, in the above case, is found by multiplying the apparent mean dispersion by 1.054. Hence the true mean dispersion in range is 62 x 1.054 = 65 yards, and in deflection is 32 x 1.054 = 34 yards.

SPOTTING MPI TO CENTER HITTING SPACE

Wide dispersion is apparent in the 10-shot salvo pictured in figure 9-3. Mathematically, however, it is correct spotting procedure to spot the MPI to the center of the hitting space. Shots 4, 5, 6, and 7 would be hits if the MPI were spotted to point C. Shots 8, 9, and 10 would fall short of the target, while 1, 2, and 3 would still be long. Therefore, the next salvo should include at least four hits and probably would have more, since dispersion, as already noted, is subject to many variables. Spotting the MPI to the center of the hitting space is a mathematical attempt to reduce the effect of dispersion variables.

As range increases, hitting space decreases, and as dispersion increases, the probability of hitting decreases. An officer detailed to duties which include spotting should know the dispersion at various ranges up to the maximum range of his battery. He can then determine the probability of hitting a target.

DESIRABLE PATTERN SIZE

If the MPI is at the desired point of impact, a pattern of small dispersion can be expected to yield the maximum number of hits. Where excessive errors creep in, however, excessive

Table 9-2

Shot No.	Dispersion	
	In range yd	In deflection yd
1	140	10
2	90	50
3	50	80
4	20	20
5	10	40
6	10	50
7	30	0
8	60	30
9	90	30
10	120	10
Sum	620	320
Mean	62	32

110.58

Table 9-3

Number of shots in salvo	Ratio of true mean dispersion to apparent mean dispersion
12	1.044
11	1.049
10	1.054
9	1.061
8	1.069
7	1.080
6	1.095
5	1.118
4	1.155
3	1.225
2	1.414

110.89

dispersion results. If the pattern is so spread that few shots are grouped around the desired point of impact a minimum number of hits is probable. From the standpoint of a maximum number of hits, it would seem desirable to eliminate errors completely so as to have a zero pattern in range and deflection. Such a pattern would be desirable if the MPI were always at the desired point of impact. It is difficult in actual firing, however, to place the MPI at this desired point. Since it would be better to hit with some of the shots than to miss with all, a larger pattern size is better.

In the Naval Warfare Information Publication, NWIP 22-2, there are tables giving the average pattern sizes for the various caliber guns. These tables were constructed from firings conducted at the Naval Weapons Laboratory. Patterns in the fleet should be no larger than those given in the tables.

ACCIDENTAL ERRORS CAUSING SHIFT OF MPI

Since dispersion of individual shots is caused by unpredictable errors, it is logical to assume that no two salvos will be exactly alike. Hence, the MPI of the shots of a given salvo can be expected to differ in location from the MPIs of other salvos.

The average shift between successive MPIs is usually so small as to be difficult for the spotter to estimate. Therefore, the spotter should not be too quick to spot when only one or two salvos seem to wander off the target during a string that is, in general, satisfactory.

CONTROL ERRORS

The only accidental errors so far considered have been those which affect individual guns of a battery. These are known as gun errors and should be distinguished from another class of accidental error which affects the battery as a whole. These are known as control errors and include errors in computing, transmitting of data to the guns, and in director fire, director pointing errors. They are not reflected in increases pattern sizes (i.e., increased dispersion among the guns) but are characterized by increased dispersion or error of the MPIs themselves.

There are four general control inaccuracies which may cause MPI error. These are listed in the order of probable frequency of occurrence and magnitude of effect:

1. Computer set up with incorrect values.
2. Ballistic corrections based on incorrect values (I.V., wind, air density, and others).
3. Battery not properly aligned with director.
4. Indeterminate errors ("Class B" and personnel errors).

Let us now consider each of these sources of control errors.

Incorrect Computer Setup

Determination of target course and speed is made directly from the spotter's estimate of target angle and speed, from CIC, or by rate controlling. Correct values of these two variables are difficult to determine; they are the chief cause of incorrect computer setup, and hence, the chief source of MPI error.

Present range to target is valid only so far as its measurement is accurate. An error in basic range measurement directly causes an error in MPI.

Measurement of own-ship course and speed usually are reasonably accurate, but any inaccuracies result in an error in MPI.

Inaccurate Ballistic Corrections

The computer determines corrections for variations from standard conditions. Determination of these corrections based on incorrect values of ballistic wind, I.V., air density, etc., will give a total ballistic correction that will result in a corresponding error in MPI.

Poor Battery Alignment

Improper alignment between the guns of a battery results in greater dispersion and larger

pattern sizes, but does not materially affect the error of the MPI of a salvo. In contrast, MPI error can be caused by misalignment between the controlling director and the battery as a whole. Such misalignment is generally caused by failure to director-check the battery and all directors. A battery aligned with one director is not necessarily aligned with another which may be in control. Frequent director checks can assist in elimination of this cause of MPI error.

Indeterminate Errors

There are two classes of indeterminate errors.

Some of the computations by mechanical computing elements in fire control instruments are only approximations of the true solutions. These approximations result in "Class B errors," which are small for normal ranges and therefore cause minimum error in MPI. However, at extremely short or long ranges the errors may become large, depending on the instrument concerned, and may seriously affect the MPI. When Class B errors are known to be large, they can no longer be treated as accidental, and steps must be taken to make correction for them.

The other class of indeterminate errors is assignable to control personnel. For example, the director pointer or trainer may be off the point of aim when the salvo is fired. Training and experience can reduce the magnitude of such mischance. Small errors of this type merely cause a slight shift of MPI and should not be corrected by the spotter. The director operator should inform the spotter of larger discrepancies in the point of aim, so that the spotter may distinguish this error from others.

ERRORS AND THE SPOTTING PROCESS

It is not enough for the spotter to detect errors, estimate the spots required, and transmit them. He must be able to recognize the causes of errors by understanding their characteristics and knowing what to expect of the batteries he is working with, and then make up his spots with this information in mind. In summary, we list below the three main types of errors that crop up in gunfire from shipboard, and what can be done about them.

1. Accidental gun errors causing dispersion of shots. These errors are only compensated to the extent of achieving desired pattern sizes. Most of the errors are eliminated by careful design, frequent checks of battery alignment, normal upkeep of the battery, and the training of gun crews.

2. Accidental gun errors causing a shift in the MPI of successive salvos. The shift in both deflection and range is usually small.

3. Control inaccuracies causing error of MPI. It is the primary duty of the spotter to "spot" the corrections in range and deflection necessary to bring the MPI of a salvo to the desired point of impact. He should recognize the first two classes of errors in order to spot the error of MPI caused by control inaccuracies.

FUNCTIONS AND DUTIES OF THE SPOTTER

The spotter has several functions and duties. In order to perform them effectively, he should have the following qualifications:

1. An even, calm temperament, not excitable under stress.
2. Sound judgment.
3. Decisiveness.
4. Alertness.
5. Normal eyesight, hearing, and speech.

PRIMARY FUNCTION OF THE SPOTTER

The primary function of the spotter is the correction of range and deflection errors of the MPI so as to bring the shots on the target. Prompt and accurate correction of initial errors may be the deciding factor in a naval engagement. He bases these corrections on his own observations combined with those of the fire control radar operator. As a rule, in good visibility the spotter will estimate the necessary deflection correction, and range corrections will be obtained from the radar. Under unfavorable conditions both range and deflection corrections will be obtained from the radar.

If radar fails, optical spotting must substitute. In the initial discussion of the spotter's problems, it will be assumed that radar is not available.

GENERAL FUNCTIONS AND DUTIES OF SPOTTERS

Besides his primary function of correcting the fall of shot, there are other functions which the spotter must perform before and during firing. In general these are:

1. Describe the enemy forces (general bearing line, number of ships, deployment, etc.).
2. If he is also acting as the control officer, he estimates the values of range, target angle,

and target speed, and keeps plot informed of all changes to these values.

3. Keep control informed of the tactical situation.

There are other duties which the spotter may be required to perform. Their exact nature will vary with different types of ships. The spotter's detailed duties and spotting procedures are prescribed in the ship's Weapons Department Organization Manual, and in fleet doctrinal publications (NWIPs etc.).

VISUAL ESTIMATE OF TARGET COURSE AND SPEED

To arrive at a solution of the fire control problem, the computer must have target course and speed. Often the spotter can obtain these data by observation through binoculars.

To determine target course, the spotter must be able to estimate accurately target angle (i.e., relative bearing of own ship as seen from the target). To estimate target angle the spotter must know the structural details of all likely targets. Silhouettes of all probable targets are furnished each ship. The spotter should study the details of these visual aids, not only for the purpose of recognizing the enemy, but also for estimating target angle. In estimating target angle, the spotter should make use of prominent objects such as bridges, breaks in the deck, stacks, masts, and other features. By observing the opening and closing of the apparent distance between such details, the spotter can estimate the angle the enemy ship makes with the line of sight.

Target speed can at best be only roughly estimated. Here again, knowledge of enemy ships is valuable, particularly as regards maximum speeds. Target speed may be estimated as about 1 or 2 knots less than the maximum speed of the slowest ship in the formation.

To make the best speed estimates you must have extensive training and experience. The aids used by a spotter in a direct estimation of target speed are smoke from the stacks, bow wave, and stern wake. A spotter who knows his target size can also make accurate preliminary estimates of range by using the mil graduations in his binoculars. (Mils are explained further in the following section.)

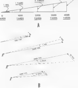
SPOTTING IN DEFLECTION

Because it is simpler to make range spots when there is no deflection error (particularly at long ranges), the spotter customarily calls deflection spots first. The unit used in deflection spotting is the angular mil.

The Mil and How to Use It

You are already acquainted with the angular mil because it is the unit in which gunsight deflection scales are calibrated. There are about 6400 mils to a circle, and 1 mil is about 0.56°, or 3.37 minutes of arc. The reason for using the mil as an angular unit in measuring deflection, rather than using degrees or minutes, is that it has a very useful property. If a distant object appears to an observer to have an angular width of 1 mil, then the actual width of the object is 1/1000th of the range.

Telescopes, binoculars, and other optical devices for naval use often have reticles with mil scales etched on them. If you use such binoculars to look at, say, a 30-foot boat broadside on at a range of 1000 yards, the image you see in the binoculars will have an angular width of 10 mils. Figure 9-4 shows further graphical examples of the relationship between mils and



55.145
Figure 9-4.—The angular mil and how it is used.

range. Part A of the figure shows how 1 mil subtends different linear distances at different ranges, and part B shows several other examples of the relationship. To bring the use of mils down from this theoretical level, look at figure 9-5. What is the linear size in deflection of salvo A's pattern?

Salvo A at a range of about 11,500 yards subtends 5 mils. One one-thousandth of the range is 11.5 yards; multiplying by 5 (mils) gives an actual pattern width in deflection of 57.5 yards. As a practical matter, of course, it's absurd to specify a pattern width down to a half yard; rounding off, the answer would be about 58 yards.

In estimating deflection spots, use target width in mils as a guide.

Allowing for Splashes

With a high speed surface target, the spotter should bear in mind that the apparent MPI in deflection should be held abaft the point of aim to allow for target travel while the splashes are forming. Do not assume that full splashes form instantaneously at the impact of a salvo. The time lag is only a few seconds at most, but is sufficient to allow considerable movement of a fast target.

SPOTTING IN RANGE

Spotting in range is more difficult than spotting in deflection. There is no convenient angular measure that is uniformly applicable at all ranges, like the almost foolproof mil.

Figure 9-5 is adapted from a typical spotting diagram. It shows schematically how different ranges look to you as an observer 100 feet above the water surface. The lateral broken lines represent ranges in increments of 1000 yards; the diagonal broken lines represent angular mils; and the curved solid line at the right shows the apparent length in mils of a 600-foot broadside target at various ranges. Unfortunately, the natural seascape is not marked with these handy reference lines, but the diagram is a helpful guide in learning how to estimate ranges. It is used in conjunction with such training aids as miniature spotting boards, and with observation during target practice.

The range lines in figure 9-5 represent angular distance below the horizon at which any object would appear from a height of 100 feet, if observed on the corresponding range lines. The distances between the range lines represent the apparent range differences as viewed by an observer at the height (in this case 100 feet) for which the diagram was constructed.

A study of figure 9-5 shows that salvo A is clearly short, by about 500 yards, of the imaginary extension of the waterline of a target at 12,000 yards. However, the error of salvo B, fired at a target at 19,000 yards, is not so apparent. The 500-yard error of salvo B is difficult to see when compared with the extended waterline of the target. Thus, for shipboard spotting at such a range, the splashes must be in line with some portion of the target before the spotter can reasonably tell whether the salvo is over or short, to say nothing of estimating the amount of the error.

In addition to its use for estimating range and range errors, the spotting diagram shows the number of mils a given target length will subtend at any given range. For example, in figure 9-5 a 600-foot target will subtend 20 mils at 10,000 yards range.

One of the most common mistakes made by the untrained spotter is to underestimate the amount of range error at long ranges, because a given range error will subtend a much smaller angle at long ranges than it does at short ranges. However, with good visibility and from a height of 120 feet or more, the MPI error can usually be estimated with reasonable accuracy at ranges up to 15,000 yards, by observing the position of the bases or slicks of the splashes relative to the target waterline.

METHODS OF SPOTTING

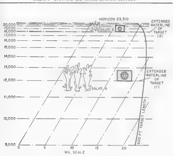
This section is concerned, primarily, with methods of visual spotting and spotting with radar. Before discussing these methods, however, we will discuss some of the terminology used in spotting.

SPOTTING TERMINOLOGY AND MESSAGE PRACTICE

As in other operational communications, there is a prescribed terminology and message sequence for spotting. These are published in fleet operational directives which you will use on active duty. The examples below show the general practice at the present time.

Surface Fire

For surface fire, only range and deflection are spotted. The correction necessary to bring



92.58
Figure 9-5.—Practice diagram for range spotting.

the MPI on target is given in the following terminology sequence.

1. Deflection correction—RIGHT or LEFT, in mils.

2. Range correction—ADD or DROP, in yards.

When no correction in deflection is necessary, only a range spot is made. When no range spot is necessary (regardless of whether a deflection spot is required), the phrase NO CHANGE is used. Typical examples of spot transmissions by telephone are: RIGHT 10, ADD 1,000; LEFT 5, DROP 300; LEFT 10, NO CHANGE; NO CHANGE.

AA Fire

For air targets, corrections to bring the burst on the target are needed in three dimensions. Even well-trained personnel find it almost impossible to estimate errors rapidly in three dimensions. AA spotting is therefore generally limited to correcting for obvious constant system errors.

The proper terminology for spotting in AA fire is as follows:

1. Deflection correction—RIGHT or LEFT, in mils.

2. Height-of-burst correction — UP or DOWN, in mils.
3. Range correction — ADD or DROP, in yards.

Deflection and elevation spots will normally be made by the control officer. Range spots will be made by the rangefinder or radar operator.

Naval Gunfire Support

In shore bombardment, as in AA fire, spots in three dimensions may be necessary. The terms are the same as in the preceding paragraph, but the units are not the same. When naval guns are used to support landing operations, joint forces are involved. The Navy, Army, and Air Force have a standardized spotting terminology for joint operations which will differ from the above in that all corrections for indirect fire are spotted in yards. Deflection and elevation spots must be converted to angular units before being applied to the computer.

Spots in three dimensions are made in the following order:

1. Deflection — RIGHT or LEFT.
2. Height of burst — UP or DOWN.
3. Range — ADD or DROP.

VISUAL SPOTTING METHODS AND TECHNIQUES

There are three methods of visual spotting:

1. The direct method.
2. The bracket-and-halving method.
3. The ladder method.

The method used depends on the type of battery firing, type of target, visibility and range.

Direct Method

Spotting by the direct method is, as its name implies, the spotting of salvos (splashes) direct to the target. This is the most desirable procedure, but its use is limited to shorter ranges and good visibility conditions. For reasonably accurate visual spotting at a range of 15,000 yards, a spotting height of 120 feet is required. The splash must be relatively close to the target, and the rangekeeper set-up fairly accurate.

A thoughtful analysis of the problem with reference to the spotting diagram in figure 9-5 reveals that the greatest limitation of the direct method in visual spotting is in range. Deflection spots can be made with equal accuracy at any visible distance. If, then, air observation is available, and the plane spots in range with the ship spotting in deflection, the direct method can be used by the battery at any range at which a portion of the splash is visible to the shipboard spotter. Air spotters cannot spot accurately in deflection unless they have a line of sight containing the firing ship and the target.

Spotting the fall of shot at very short ranges differs from other spotting problems in that range errors are not difficult to judge. However, in determining deflection errors at short ranges, consideration must be given to the travel of the target and the spotter's position relative to the line of projectile flight. For example, with the firing ship and target on opposite courses, target to starboard, a shot fired with correct deflection but long in range will appear to the spotter to be in error to the left of the target. Special short-range splash diagrams aid the spotter in this type of firing.

Bracket-and-Halving Method

Bracket-and-halving is used at long ranges when no air or radar spot is available. At great distances it is impossible to tell if a splash is short of or over a target, unless the two are in line. If the splash and target are not in line, the first spot is made in deflection only. When target and splashes are in line in deflection, a range spot is made in such a direction and amount as to "cross" the target definitely. The direction of the next spot is reversed, and the size of the spot is cut in half. This "halving" is continued until a straddle is obtained, at which time it may be appropriate to shift to rapid partial salvo or to rapid continuous fire. The spot should not be reduced below pattern size.

The Ladder Method

When ranging is difficult and visibility poor because of fog, smoke, or darkness, the ladder technique is valuable. Ladders are not particularly adaptable to fast-moving targets. There are many variations of this technique, but the basic procedure is:

1. Fire is deliberately opened short.
2. Succeeding salvos are fired to approach the target in steps not less than pattern size.
3. As soon as the target is crossed, the steps are reversed and halved until the target has again been crossed.

After the target is straddled, a rocking ladder may be used with slow timed fire, or with rapid partial salvo or continuous fire. In a rocking ladder the pattern is shifted back and forth across the target by small arbitrary successive spots, such as +100, 0, -100, ... introduced at the computer. Its effect is to increase the pattern size, which may be valuable when firing against a target capable of rapid maneuvering. The rocking ladder can be used in conjunction with air or radar spotting, so long as the spotter is kept informed that this technique is being used.

SPOTTING WITH RADAR

Radar spotting has proved to be both accurate and reliable within the range of surface batteries. Radar provides a means of spotting which is independent of conditions of visibility, so that blind spotting is possible with blind firing.

Shell splashes appear on the scope as fluctuating echoes which last for several seconds, depending on the size of the projectile and the range. The large column of water thrown up by the projectile produces the echo. Salvos produce larger or multiple echoes on the scope.

If the projectile stays within the vertical limits of the radar beam, its flight to the point of impact can be followed on the scope on main sweep. The projectile produces a small, weak, moving echo which begins at the edge of the scope and moves out in range toward the target. At the point of impact the echo stops and grows larger as the splash builds up. Echoes from direct hits or near misses will be lost in the target echo, while salvos which straddle the target may envelope the target echo in the midst of the splash echoes on the scope, thereby making it impossible to distinguish individual splashes. Range errors can usually be estimated by radar with greater accuracy than by optical spotting, but deflection spotting with radar is difficult, especially when the error is small. Near misses sometimes merge with and are indistinguishable from the target pip. Consequently, repeated salvos can land with a 2-mil to 5-mil error which is not separately distinguishable but may not be hits. Target practice is used to determine the minimum deflection error that can be detected on a particular radar. When radar is the only means available for deflection spotting, deflection "rocking ladder" should be used. The order of preference in spotting surface fire is usually: RANGE—radar, air, and visual; DEFLECTION—visual, radar, and air. In night action, or action under reduced visibility, radar normally spots for both range and deflection.

SPOT PYRAMIDING

SPOT-PYRAMIDING is the application of a new spot before the effect of a previous spot has had time to become apparent. It can occur only in rapid fire, when the interval between shots or salvos is less than the time of flight plus the spotting interval. In that case, when a salvo lands there are one or more other salvos in the air. Suppose the spotter makes a spot on the salvo which has just landed. This spot is applied and a new salvo is fired. Then one or more of the salvos which were already in the air lands, and the spotter, forgetting that his previous spot has not had time to show its effect, spots again. This spot is applied to the next salvo fired, with the result that this salvo is overcorrected and will probably miss, as will subsequent salvos until the spotter sees his mistake and spots back again.

The time of flight clock signal helps to avoid pyramiding. A button on a mechanical time clock is pressed in the plotting room when the salvo on which a spot is applied is fired. The clock has been preset to ring just before the time of flight of the projectile ends. Before the salvo lands, the mechanism sounds a buzzer. This is then relayed to the spotter via sound-powered phones.

Because spot pyramiding is common and has a disastrous effect on accurate control of fire, the means used to prevent it must be carefully and correctly operated. For example, if the time-of-flight mechanism operator forgets to press the button for a spotted salvo, and the spotter waits for the signal, he may continue to wait after it becomes apparent that his previous spot was incorrect.

When modern fire control systems are being used to solve the fire control problem, the process described in chapter 6 as rate control is used to make constant corrections to the solution. If spots are applied at the same time as rate control corrections, the effect is the same as pyramiding of spots. Under normal circumstances, AA fire is rate controlled. Hence spotting of air bursts is rare.

SHORE BOMBARDMENT AND NAVAL GUNFIRE SUPPORT: FUNDAMENTALS

In World War II, naval task forces frequently carried out bombardments of enemy installations

on shore. After the ineffective results noted during the Tarawa operation in November 1943, shore bombardment techniques were gradually improved through successive landings at Roi-Namur, Eniwetok, Saipan, Guam, Peleliu, the Philippines, Iwo Jima, and Okinawa. Later, the Korean War and the Vietnam conflict gave frequent opportunities for the refinement of the techniques learned in World War II.

An opposed amphibious landing is one of the most hazardous types of military operations. Until World War II, many military authorities believed that such an operation was too hazardous to be attempted. In part, this belief was based on the Allied failure in the amphibious Dardanelles (Gallipoli) campaign during World War I. Analysts ascribe the failure at least partially to inadequate naval preparation before the campaign.

To be successful, naval gunfire support for amphibious operations must be carefully planned in advance, and must be executed with skill and dispatch. It is vitally important in the period after the troops have landed but before adequate artillery can be brought into action. Its full exploitation can be achieved only if ground, naval, and air personnel understand the organization, basic techniques, capabilities, and limitations of naval gunfire support, and follow the standard procedure which has been agreed upon by the joint services.

PURPOSE OF SHORE BOMBARDMENT AND NAVAL GUNFIRE SUPPORT

Naval gunfire is delivered from ships' batteries not only in support of troop operations, but also to support related naval and air operations, such as mine warfare activities, air-sea rescue operations, reconnaissance and demolition operations, demonstrations, feints, raids, flak suppression during air strikes, and interdiction of coastal roads, railroads, airfields, and troop assembly areas. All these activities rest on the same basic principles as the naval gunfire support of amphibious operations.

The basic task of naval gunfire support units in an amphibious operation is to support the seizure of the objective by destroying or neutralizing:

1. Shore installations that oppose the approach of ships and aircraft to the objective.
2. Defenses that may oppose the landing.
3. Defenses that may oppose the postlanding advance of troops.

These tasks are carried out in the preparation of the objective for the landing, the support of the landing, and in postlanding support.

This section takes up the fundamentals of naval gunfire against shore targets, both in support of troop operations and for other purposes.

TERMINOLOGY: GUNFIRE CLASSIFICATION

Naval gunfire against land targets may be classified in various ways. The classifications are interrelated; terms from several types of classification must be used for a full description. These classifications are based on:

1. Effect sought:

a. DESTRUCTION. Deliberate and accurate fire, usually delivered at short range, for the purpose of destroying a target, usually a material object.

b. NEUTRALIZATION. Rapid, fairly accurate fire delivered for the purpose of hampering, interrupting, or preventing enemy fire, movement, or action. Destruction of weapons and personnel is secondary. The effect of neutralization is comparatively temporary; such fire may have to be repeated.

c. HARASSING FIRE. Sporadic fire delivered during otherwise quiet periods to prevent enemy rest, recuperation, or movement, and in general to lower enemy morale and combat efficiency.

d. INTERDICTION FIRE. Fire designed to prevent or curtail the use by the enemy of an area, bridge, defile, airfield, route of communication, etc.

e. ILLUMINATING FIRE. Gunfire employing illuminating projectiles (star shells) to illuminate the enemy, to detect his movements, to aid our own observation, or to facilitate own troop movements.

2. Tactical use:

a. CLOSE SUPPORTING FIRE. Gunfire delivered on enemy targets which, because of their proximity, present an immediate and serious threat to the supported unit. (Close supporting fire may be as close to friendly troops as 300 yards enfiladed, or 600 yards when the target axis is not parallel to the line of fire.)

b. DEEP SUPPORTING FIRE. Gunfire delivered on objectives not in the immediate vicinity of friendly forces, to neutralize or destroy enemy reserves and weapons, and interfere with

enemy command, supply, communications, and observation.

c. PREPARATION FIRE. A heavy volume of prearranged neutralization fire, delivered just prior to a landing or a ground attack by friendly forces on enemy positions.

d. COUNTERBATTERY FIRE. Gunfire delivered against active enemy guns and fire control stations for the purpose of silencing the guns.

e. PREARRANGED OR SCHEDULED FIRE. Gunfire formally planned and executed against targets of known location. Such fire is usually planned well in advance and is executed at a predetermined time.

f. CALL FIRE. Gunfire delivered at the request of troop units ashore, or of some spotting agency. Call-fire missions must not be interrupted without permission of the unit requesting the fire, except in case of emergency.

g. OPPORTUNITY FIRE. Gunfire delivered without formal planning or troop request on newly discovered targets, or upon transitory targets. Targets of opportunity may present themselves to the firing ship at any time, but fire must be delivered only with due regard for safety of friendly troops. Ships executing deep support missions must assure themselves that the target of opportunity is within their assigned sector of responsibility.

h. RECONNAISSANCE FIRE. Gunfire delivered in areas where camouflaged positions are suspected or in vital areas where natural cover prevents observation and/or gathering of photo intelligence.

i. FLAK SUPPRESSION FIRE. Gunfire used to suppress AA fire immediately prior to and during an air attack on enemy positions.

3. Technique of delivery:

a. DIRECT FIRE. Gunfire delivered on a target by using the target itself as a point of aim for laying the guns or director. Direct fire is usually used on targets which can be seen (by optics or radar) from firing ship.

b. INDIRECT FIRE. Gunfire delivered on a target which is not itself used as a point of aim for laying the guns or director. Indirect fire is always used on targets not visible from the ship. This fire is spotted by air spotters or shore fire control party spotters assigned for this specific purpose.

4. Type of fire:

a. AREA FIRE. Gunfire delivered in a prescribed area. Area fire is generally neutralization fire.

b. POINT FIRE. Gunfire directed at a definite material target in order to destroy that particular target.

c. DEFILADE FIRE (reverse-slope fire). Gunfire delivered on targets located behind some terrain feature, such as a hill or ridge, which masks the target (fig. 9-6A).

d. ENFILADE FIRE. Gunfire delivered on a target in such a manner that the range pattern of the fall of shot coincides with the long axis of the target (fig. 9-6B).

TERMINOLOGY: GENERAL TERMS

Some other general terms used in naval gunfire support operations are:

1. AMPHIBIOUS TASK FORCE. A task organization under naval command composed of assault shipping, embarked troops, and supporting naval units and tactical air units.

2. AMPHIBIOUS TROOPS. Troop elements assigned to an Amphibious Task Force.

3. ADVANCE FORCE. A task organization of ships which conducts operations such as reconnaissance, minesweeping, underwater demolition, diversionary raids, and preliminary bombardment prior to the arrival of the main body of the ATF in the objective area.

4. ATTACK GROUP. A subdivision of an ATF, consisting of assault shipping with embarked troops and supporting naval and tactical air units operating to establish a landing force on shore and support its operations thereafter. In an operation involving only one Attack Group, it is also the Amphibious Task Force.

5. FIRE SUPPORT UNIT. A group of ships, part of the Attack Group, assigned the mission of naval gunfire support to an amphibious operation.

6. OBJECTIVE AREA. A defined geographical area within which is located the objective to be captured or reached by the military forces.

7. OBJECTIVE. A physical area or location on the ground, usually a readily identifiable terrain feature, which a troop unit is assigned to capture or occupy. Objectives may be designated as intermediate or final objectives.

8. D-DAY. The day on which an amphibious landing takes place.

9. H-HOUR. The actual time to the minute at which the leading wave of the landing force

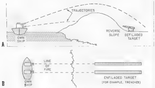


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Figure 9-6.—Types of target.

touches down on the beach; if actual H-hour differs from scheduled H-hour, the actual time of H-hour is broadcast to all ships and troop units by the Amphibious Task Force Commander.

10. ZONE OF RESPONSIBILITY (ZR). The land in the objective area is divided into zones assigned to fire-support units or to individual ships which are responsible for observing, destroying, or neutralizing known enemy installations and for attacking targets of opportunity therein. A ship may fire in its own ZR without clearance from any troop unit, providing the target is not short of an established coordination line. The boundaries of the zone of responsibility should be recognizable both on the terrain and on the map. The boundaries of zones of responsibility of direct support ships should correspond to the zones of action of the landing force units supported. These zones include all land area in the vicinity of the landing forces except the Close Support Area.

11. PRELIMINARY BOMBARDMENT. Bombardment in the objective area delivered by an Advance Force prior to arrival of the main body of the ATF, with the primary purpose of destroying enemy defenses which might hinder or abort the landing.

SHORE BOMBARDMENT AND NAVAL GUNFIRE SUPPORT: FIRE CONTROL

Naval vessels perform shore bombardment missions either in coordination with troop operations (such as amphibious landings, assaults, or—to a limited degree—offensives) or independently (but in coordination with other naval or air units) for such miscellaneous purposes as interdiction or destruction of selected targets. This section takes up the fire control aspects of shore bombardment methods and techniques. A later section concentrates specifically on shore bombardment operations in preparation for and coordinated with troop operations.

FIRE CONTROL ASPECTS OF SHORE BOMBARDMENT

So far as fire control is concerned, naval gunfire against stationary land targets presents much the same problem as firing at a ship dead in the water (or, with respect to terrain features at a significant elevation above sea level, at a helicopter hovering at fixed altitude over a specific point). The following special aspects of the problem are worth noting:

1. Ship's Position. The geographical position of the firing ship must be continuously and

accurately fixed, as from this are determined the range and bearing of the target in many instances when indirect fire must be used.

2. Current Effects. The set and drift of the current will affect the solution of the fire control problem. When determined, drift may be entered into the computer as target speed; the direction of the set is reversed and introduced as target course.

3. Parallax. Unlike normal gunnery practice at sea, it is often necessary to increase the salvo pattern in deflection in order to cover land targets of large area. One method of doing this is to eliminate horizontal parallax correction by setting horizontal parallax correctors at the gun mounts at infinity (i.e., for a target at infinite range) so that gun bore axes are parallel for any specific range.

4. Terrain. Fire control techniques discussed in chapter 6 took into account only own ship and target and the location and velocity of target with respect to own ship. This is necessary because the featureless seascape and the unmarked airspace provide no reference points. On land, however, there are reference points that can be used to assist in laying the guns on target, and in preventing fire on friendly troops, vehicles, and installations. In addition, terrain features complicate correction of the fall of shot. Since solutions assume the point of fall to be in the horizontal plane, the elevation of the target above sea level must be considered in the solution. Figure 9-7 illustrates the errors resulting when the range of a land target is taken from a chart and the target's elevation is not considered. Terrain features also affect the size of the pattern in range; a forward slope decreases it, and a reverse slope increases it. Figure 9-8 illustrates these effects. Consequently, it is clear that shore bombardment almost always involve the use of maps and charts to an extent rarely required in other types of naval engagements.

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Figure 9-7.—Errors resulting from failure to compensate for target elevation.

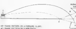

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Figure 9-8.—Effect of terrain slope on the range pattern produced by ship's guns.

MILITARY GRID REFERENCE SYSTEM

Rapid and accurate means for designating the location of targets are important in shore bombardment. Particularly in naval gunfire support of troop operations, it should be obvious that the troop unit supported and the supporting ship must use a common map. Although they need not be of the same scale, and seldom are, the target maps must be identical regarding terrain features and the method of locating points thereon. Like other techniques of naval gunfire support, the development of a system of target location designations has passed through several stages, following generally a grid-system method. In this method, the land and sea areas at the objective are divided into squares by north-south and east-west lines, which are numbered. These lines are called grid lines.

The Military Grid Reference System imposes vertical and horizontal reference lines over a projection of the earth's surface. Its purpose is to simplify and to increase the accuracy of reporting and plotting in military operations. This grid reference system is based on two projections; the Universal Transverse Mercator (UTM), and the Universal Polar Stereographic (UPS). The UTM is used in the area between 80° south latitude and 80° north latitude; the UPS is used in the polar regions of the earth south and north of these limits. The UTM system divides its area of the earth into a grid pattern with each rectangle in the grid 6° from east to west and 8° from north to south. (Because the grid is rectangular but the earth's surface is not flat, there is some distortion in maps based on the grid, but in any single rectangle this distortion is negligible.)

Each rectangle is called a grid zone, and is designated by a letter and a number (e.g., 2P, 5M, 52S, etc.). The grid zones are broken down

into squares 100,000 meters on a side. These are further subdivided, with the smallest subdivision a 100-meter square. The 100,000-meter square is identified by letters only. In the examples below, CU identifies the 100,000-meter square, and 52S identifies the grid zone. The subdivisions of the 100,000-meter square are systematically identified by letters and numbers, so that in theory any 100-meter square spot on earth can be designated by its number-letter code. This code is called a military grid reference, and it consists of a group of letters and numbers which indicate (1) the grid zone designation, (2) the 100,000-meter square identification, and (3) the grid coordinates; that is, the numerical reference of the point expressed to the desired accuracy. Examples:

52SCU . . . . Locating a point within a 100,000-meter square.
52SCU65 . . . . Locating a point within 10,000-meter square.
52SCU6957 . . . . Locating a point within 1,000 meters.
52SCU693576 . . . . . . Locating a point within 100 meters.

As a matter of practical referencing in a shore bombardment problem, both the grid zone designation and the 100,000-meter square identification are generally omitted. The UPS system in similar fashion permits location and identification of any 100-meter square on the earth's surface near the poles.

Fire-support ships are provided with approach charts and bombardment charts for use on their dead-reckoning tracers. (A dead-reckoning tracer or DRT is a mechanical plotting device, usually located in CIC, that will trace own ship track on a chart or plotting paper to any of a range of scales desired, using as inputs own ship course and own ship speed.) These charts are complete in hydrographic as well as topographic detail, and both have a grid system overprinted on them. These charts are of particular use in indirect fire, to be discussed later.

METHODS OF FIRE AT LAND TARGETS

In conventional gunfire control as described in chapter 6 the target is visible from the ship, either optically or by radar. But this is not always true of land targets; much of the firing any ship performs in shore bombardment will be at targets that nobody on the ship can see through a telescope or a radarscope. Fire at a visible target is called direct fire; fire at an unseen target is indirect fire.

Direct Fire

Targets visible from the firing ship offer the simplest fire control problem to the ship, and their destruction is easier than targets which require indirect fire. Such visible targets are: point targets, counterbattery targets, targets of opportunity, or area targets. When the target can be seen, the director can furnish accurate target bearing and elevation. These, with a present range which can be measured, ensure an accurate fire control setup which should result in early hits. Direct fire is controlled as it would be for fire against enemy ships except that when the ship is providing call fire support, the fire will be directed, controlled, and spotted by the shore spotter.

Indirect Fire: Use of Bombardment Charts

Indirect fire is employed against targets that cannot be seen by the firing ship. Given an accurate bombardment chart and knowing the exact position of own ship, it is possible to measure range and bearing to any land target that has been designated in advance, and to hit that target without using the director or rangefinder.

The ship's position is accurately determined by navigational methods, using positively identified landmarks, and is plotted on the bombardment chart. Since own ship's course and speed are known, future position may be projected ahead along the ship's track by dead reckoning. As in direct fire, because own ship's speed is usually slow (less than six knots), the set and drift of the currents frequently contribute as much movement to own ship as do the propellers. To generate an accurate solution it is essential to use total movement of own ship. To ascertain own ship's speed, CIC keeps a continuous plot by navigational methods; after several plots have been made, the distance traveled is measured against time and an accurate value of speed is calculated. This speed is set into the computer by hand as target speed, and own ship's speed is set to zero. Target course is then set in manually as the reciprocal of drift or true ship's course.

Future positions are projected ahead along the ship's track on the DRT. A future position is chosen, usually one minute ahead, and from this point bearing and distance to the target are

picked off the chart. These values of range and bearing are sent to plot and set into the computer manually. When the ship passes the position chosen, the plotter in CIC gives a "MARK" and the time motor of the computer is turned on. The plotted and computed values of range and bearing are then checked by "MARKING" every 15 or 30 seconds. If the range and bearing agree within reasonable limits (100 yards and 1/2 degree), plot is ready to fire. If not, the check procedure is repeated and the bearing and range in the computer are corrected until the setup is correct. Plot is then ready to shoot after reporting the gun target line (line between firing ship and target) to the shore fire control party.

Indirect Fire: Point Oscar Method

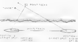
This method of indirect fire was devised primarily for ships with fire control systems incapable of correctly generating range and bearing to a designated grid point. Its use, however, even by the newest ships is advantageous under certain conditions, such as when no shore spotter or air spotter is available for observing the fall of shot. The method requires a visible point of aim (designated "Point Oscar") near the target, as well as the accurate location of the target and Point Oscar on a map.

In practice, the director line of sight is kept continuously trained and ranged on the point of aim (Point Oscar) to give a continuous range and bearing solution to this point. Salvos are initially fired at Point Oscar as a check on the gun ballistic, and as soon as the mean point of impact has been spotted to hit, range and deflection spots necessary to hit the invisible targets are applied.

Since the motion of the firing ship continuously changes the values of the offsets from the point of aim, frequent changes in these offset spots must be made to ensure hitting the target. This problem is illustrated in figure 9-9. One way to determine correct range and deflection spots continuously is to use a small transparent overlay on which are inscribed 100-yard squares drawn to the same scale as the chart. With the center of the gridded overlay on Point Oscar, and the grid lines oriented to the direction of the line of sight from the ship, range and deflection spots to hit the designated target may be read directly from the grid overlay.

Indirect Fire; Radar Beacon

The radar beacon is a portable transmitter-receiver, set up by the shore fire control party,



36.31

Figure 9-9.—Point oscar method of indirect fire, showing necessity for continuous changes in offset spots to hit target.

capable of emitting a characteristic signal when keyed by the transmitted pulse of the ship's fire control radar. This signal is different in frequency from the transmitted pulse, to eliminate the normal echo returns from the shore. The signal is received by the fire control radar when the radar receiver has been tuned to receive the beacon frequency. Extremely accurate ranges and bearings to the beacon may be obtained. It can be tracked manually or in automatic radar control.

The radar beacon is used primarily to aid in the delivery of accurate naval gunfire under all conditions of visibility and to eliminate the errors of normal navigational plotting, using landmarks and other visual navigational aids.

Indirect Fire; Defilded Targets

Targets which are located on the far slope of a hill or ridge between firing ship and target present a particularly difficult problem to the flat trajectory of naval gunfire. The projectile must clear the crest of the hill but fall steeply enough to hit the target beyond. In this situation (defiladed target) an angle of fall must be chosen which is greater than the angle of the reverse slope. Two solutions are then available. The ship may either increase the range or it may use reduced-velocity charges at shorter range to obtain this selected angle of fall. Figure 9-10 illustrates this problem and its solutions. A is the trajectory produced by standard service charges and is too flat; B is the trajectory which can be obtained by using reduced-velocity

12.23
Figure 9-10. — Problem of hitting a defiladed target.

charges; C is the trajectory which can be obtained with standard service charges by increasing the range.

If the ship must fire over friendly troops on an elevated position between firing ship and the target, it is necessary to determine target elevation, the elevation of the troop position, and the differences between the two.

Indirect Fire: Functions of CIC

The primary function of CIC in naval gunfire support is to keep an exact check on the ship's position and from this to determine ranges and bearings to targets designated for indirect fire. Accuracy of fire, when using the method previously described, depends primarily on the skill of the CIC team. CIC also keeps a record of own troop front-line positions, target locations, and other information pertinent to the support of the troops ashore. It acts as the clearing house for information to and from the shore fire control party and air observer, with whom it has direct voice radio communication. In naval gunfire support, CIC keeps the ship's commanding officer, weapon control, and plot advised regarding the requirements for support; furnishes the information necessary to provide the support; and gives the shore fire control party such information as necessary. In addition to target range and bearing, CIC must determine, from contour lines of the bombardment chart, the elevation of the target above sea level and send this to the plotting room so that range error resulting from this elevation may be corrected in the computer.

On cruisers these functions of CIC are often performed in a section of the plotting room. This leaves the ship's CIC free for other duties it must perform.

SPOTTING IN SHORE BOMBARDMENT

The principles of spotting as discussed earlier in this chapter apply in shore bombardment spotting, but procedures are different when spots are made by a fire control party ashore.

A spotter ashore must be located where he can best observe the fall of shot. Usually this requires him to be as close as possible to the target; this can present him with a very serious frontline problem of survival. He also has an alignment problem. Spots made by an observer aboard the firing ship are naturally oriented to the line between the firing ship and target (GTL). Spots made from aircraft can be oriented readily to the gun-target line, since both the gun and the target are normally within the aircraft observer's field of vision. But spotters ashore are frequently unable to see the firing ship and, so long as they are required to make their reports in relation to the gun-target line, the value of the information sent by the spotter to the ship is limited.

To simplify this problem for the spotter, the target-grid system for use in spotting the fall of shot on land is used. The target-grid system is part of the standard spotting and general shore bombardment procedure for use within the naval service.

C39.59
Figure 9-11. — Target-grid spotting problem.

The system permits the observer to spot the fall of shot just as he sees it along his own line of sight to the target (called the observer-target line), irrespective of the position of the firing ship and of the gun-target line. The procedure is briefly outlined as follows (fig. 9-11):

1. The observer, in his call for fire, must give the bearing from himself to the target—direction OT in the illustration.
2. The observer makes all his observations and corrections with respect to the observer-target line (OTL).
3. The CIC or plotting room crew converts the corrections of the observer to corrections with respect to the gun-target line (GTL).
4. The plotting room crew introduces into the rangekeeper (computer) the spots corrected to the gun-target line.

The concrete example which figure 9-11 illustrates is explained in the next section below.

APPLICATION OF THE TARGET-GRID SYSTEM

As stated in the preceding section, the target-grid system permits the ground observer to call his spots with respect to his own line of sight (OTL in figure 9-11), while spots introduced into the ship's fire control system are stated with respect to the ship's line of fire. The practical application of the target-grid system depends on quick, accurate conversion from spots in terms of the observer's line of sight (OTL) to spots in terms of the line from gun to target (GTL). This is done graphically by the grid spot convertor, which superimposes a set of coordinates based on OTL upon a set based on GTL.

The converter (fig. 9-12) consists of a transparent circular plastic disc secured by a pivot at its center to a rectangular white plastic piece. Each is printed with a square grid pattern, with the squares on both pieces of equal size, with the words LEFT and RIGHT on either side and the words ADD and DROP on the upper and lower parts. The grid lines on both pieces are numbered; each square represents an increment of 100 yards.

The grid pattern on the white plastic piece is printed in black and inscribed in a circle graduated counterclockwise in degrees; this represents the reference grid for own ship. On the 0-180° line of this pattern is a black arrow. At the top of the own ship pattern appears an additional degree calibration for introducing magnetic variation correction.

The transparent pivoted disc has its grid pattern printed in red; the circumference of its circle (which is concentric with that of the own-ship pattern) is graduated counterclockwise in mils. A red arrow is on the 0-3200 mil line. This is the reference grid for the observer.

The procedure for using the converter is explained below. Figure 9-12 shows the converter set up for the problem illustrated in figure 9-11. Figure 9-11 shows in red the part of the grid pattern that relates to the observer's spots; the black grid pattern relates to own-ship line of fire. Magnetic variation is assumed to be zero.

The procedure is as follows:

1. The converter operator obtains the true azimuth of the GT line in degrees by reading the true target bearing from the computer. He makes a mark with a grease pencil at this azimuth on the lower (black) disc. He then obtains the azimuth of the OT line in mils from the observer (spotter) via CIC. He makes a mark at this azimuth on the upper (red) disc.
2. The operator then rotates the upper disc until the two pencil marks match. (In the figure, GTL is 140° and OTL is 1500 mils.) The red and black arrows now indicate the angular relationship of the observer's line of sight and the ship's line of fire.
3. When a spot is received, the operator starts at the center of the upper disc, which represents the burst, and plots the observer's spot, "Right 300; drop 100," on the observer's reference grid (red), with each square representing 100 yards. The point plotted then represents the target, which is marked with grease pencil.
4. He now goes back to the burst (center) and counts off the squares to the target point as projected onto the lower disc (own ship reference grid). This gives a spot with reference to the ship's line of fire of "Right 250, add 200." This is the spot which is applied to the computer. (R250 is in yards, and must be converted to mils before it can be applied.)

Rectangular coordinate computers, such as Mk 47 and Mk 48, operate on the x/y coordinate principle. Spots are applied as North (y) or South (-y) and East (x) or West (-x) values. Instead of the gun target line, the y axis is used as the reference. This requires that the Grid Spot Converter be changed as shown in figure 9-13. Along the y axis, 0° is labeled as North and 180° as South; along the x axis, 090° is labeled as West and 270° as East.

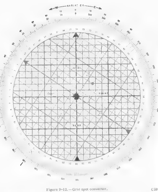


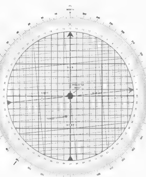
Figure 9-12.—Grid spot converter. C59.100

The procedure for spot conversion using the x/y coordinate principle is as follows:

1. Using the same problem as before, mark OTL at 1500 mils on the upper (red) disc (fig. 9-13).
2. Rotate the upper disc until the OTL (1500-mil mark) is aligned with the y axis (North or 0).
3. Plot the received correction on the upper (red) disc as right 300, drop 100.
4. Read converted correction from lower (black) disc as West 75, South 300.

COMPUTERS USED SPECIFICALLY FOR SHORE BOMBARDMENT

Shore bombardment computers are electronic plotting computers which operate in conjunction with the fire control computers in solving the



C09.100(110B)
Figure 9-13.—X/y-coordinate grid spot converter.

gunfire support problem. They are primarily an electronic DRT, which continuously solves for ranges and for bearings to the target, eliminating all manual plotting. They are fast and give more accurate results. They are particularly effective when used in conjunction with the radar beacon. Some cruisers and new construction DD's are equipped with these computers.

Primarily an "indirect" fire control device, a shore bombardment computer permits blind firing directly from bombardment charts. Figure 9-14 shows the relationship between the shore bombardment computer and the main battery fire control system. The computer provides no ballistic data. It fits into the main battery or 5-inch fire control system between the gun director and the ballistic computer. It receives from the navigating or reference director continuous values of bearing and range to a reference point of aim (either a shore target or a radar beacon). These values establish own-ship position and control the plotting head which continuously indicates ship's track. The tracking head moving underneath a map or the target by means of handcranks automatically inserts the offset between the reference point and target.

The computer then computes the bearing and range to the target. These are transmitted to the ballistic computer, which is operated in the normal manner. The height of the reference point and the target are manually set and used to convert slant range to ground range, and vice versa. Basically, the computer is a triangulation computer which continuously converts bearing and range to a reference point into bearing and range to an offset target.

Since the gun directors train in the deck plane, and thus transmit deck plane bearing information, it is necessary to correct both reference point bearing and target bearing for deck tilt. The computer also computes stabilization signals of level and crosslevel and an aided tracking signal to the navigating director.

Now let us compare the two methods of firing indirect shore bombardment (CIC giving us navigational data and the shore bombardment computer methods). First, let us consider the time element. In the older CIC method it took longer to get a solution because the information had to be plotted on the DRT, relayed to the fire control plotting room by telephone, the put in the computer by hand. In using the shore bombardment computer, inputs of range and bearing are automatic; hence, we have a more accurate first salvo solution in less time. Another factor is that set and drift are no longer required, since the shore bombardment computer will automatically and continuously compute own ship's position.

Greater accuracy is obtained by using the shore bombardment computer. This is possible because the bombardment chart is laid out on the computer (with inputs in North-South/East-West coordinates), and the fire control radar (instead of the navigational or surface search radar) is used to establish a known range and bearing reference.

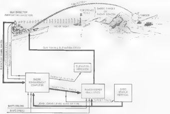
The computer under discussion is the Mk 48. The Mk 47 computer is similar in shore bombardment capabilities; however, it also can be used advantageously in AAW.

SHORE BOMBARDMENT AND NAVAL GUNFIRE SUPPORT: COMMUNICATIONS

Communications in shore bombardment is mainly external. Therefore, only the external aspect of this complex subject will be discussed in this section, and then only briefly. This section can do scarcely more than acquaint you with one corner of this ramified speciality, and even this corner cannot be thoroughly explored here—only surveyed rapidly with attention to a few essentials. Two- or three-day shore bombardment schools are available within the fleet for instructing a ship's "team" in the specifics of shore bombardment communications and procedure.

Figure 9-15 illustrates schematically the communications net (i.e., the participating stations) for a single ship in support of a battalion of troops ashore. The weapons liaison officer (WLO) aboard a ship is located in CIC, where he is connected by battle telephone with plot and the main battery director (the officer usually wears the phones himself) and by radio with the other stations in the net. Most often the radio contact is by voice radio-telephone (R/T) rather than by continuous-wave (CW) code transmission. The officer's voice does not go on the air; he communicates through a radio-telephone operator (not shown in the figure) in CIC, who functions as his talker and also logs the spots and other information received as he gets it.

The radio-telephone transmissions are usually frequency-modulated in the very-high-frequency (VHF) band (e.g., 30 to 300 megahertz) or ultra-high-frequency (UHF) band (e.g., 300 to 3,000 megahertz), although other bands may be used. The shore fire control party uses a portable battery-powered transceiver that can be carried



110.92
Figure 9-14.—The shore bombardment computer.

on the back of one man. With a low power output—which is all that is possible in such equipment—the range is only a few miles, but this is all that is necessary.

The air spotter is usually in a relatively low-speed spotting fixed-wing aircraft (often a light civilian-type one- or two-place plane) or in a helicopter. The spotter and his shore fire control party are in a forward position where they can observe the target area. The naval gunfire liaison officer is usually in a location farther from the target area.

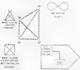
Most of the communication takes place between the spotters and the ship. The naval gunfire liaison officer sets up the net but in general does not participate directly in its functioning unless components in the net are changed, or unless it is necessary to control it for other reasons.

In general, so far as shipboard communication operations in shore bombardment are concerned, if communications are carried on through CIC, CIC follows these procedures:

1. Locates on the chart the target assigned by the shore fire control party.
2. Furnishes bearing, range, and elevation to control and plot.
3. Checks the computed solution with CIC's plotted solution.
4. Relays spots received from the shore fire control party to control and plot.
5. Plots forward lines continuously and accurately.

SPECIMEN OF SPOTTING COMMUNICATIONS OPERATION

To illustrate an instance of the use of external communications in shore bombardment, table



110.93
Figure 9-15.—Shore fire control spotting net, Schematic.

9-1 shows a specimen of the voice communication between shore spotter and ship in a simple spotting operation.

The ship's code name is RIFLE; the spotter's code name is EYEPIECE. The communications setup resembles that in figure 9-15 except that there is no air spotter and the naval gunfire liaison officer does not participate in the proceedings quoted in table 9-2.

SHORE BOMBARDMENT AND NAVAL GUNFIRE SUPPORT: OPERATIONS

Naval gunfire has many capabilities, advantageous for troop support in landings, which conventional land artillery does not possess. These include:

1. AVAILABILITY. Gunfire support ships are continuously available before, during, and after the landing, as long as the zone of action ashore is within the range of the ship's guns.

2. MOBILITY. Within the limitations of navigation, ships can move rapidly from one area to another as the situation ashore develops. At the same time, the most favorable ranges and lines of fire can be fully exploited, and enemy counterfire can be evaded.

3. HIGH RATE OF FIRE. Power loading and mechanical ammunition supply make it possible to deliver a large volume of fire in a short time. This characteristic is of great value in neutralization missions, where it is necessary to saturate the target area with a large volume of fire.

4. HIGH MUZZLE VELOCITY AND FLAT TRAJECTORY. Naval guns, particularly those of heavy caliber, have great penetration and destructive power, especially against installations presenting vertical surfaces.

5. SMALL DEFLECTION PATTERN. The comparatively small dispersion in deflection of naval guns makes them valuable for close support of troops when the line of fire can be made parallel to the troops' front line (enfilade fire; figure 9-6B).

LIMITATIONS OF NAVAL GUNFIRE SUPPORT FOR TROOP OPERATIONS

Tactical employment of naval gunfire in support of troops also has certain limitations, which must be considered in both planning and operational stages. The most important are:

1. Necessity for observation. Naval gunfire, except for area fire on very large targets, must be observed and corrected to be effective. This requires a spotting agency, such as a ground, air, or shipboard spotter.

2. Navigational limitations. Ships are forced to remain in safe, navigable, mine-free waters, and therefore sometimes cannot take advantage of the positions most favorable for the attack of targets. In some cases, ships cannot fire at all on certain defiladed (located on a reverse slope) targets (fig. 9-6A). Obviously, the maximum range inland is limited by the position of the ships, as well as by the characteristics of the weapons used. Further, the fact that the ship is in motion requires the continuous and accurate fixing of the ship's position for delivery of fire on targets not visible from the ship.

3. Communications limitations. Radio and visual communications between ship and shore are not as flexible, reliable, or secure as communications by wire or telephone.

4. Limitations of pattern. By comparison with artillery, naval guns have a small deflection pattern, a large range pattern, and a flat trajectory. This is an advantage in some respects, but requires careful selection of lines of fire when engaging targets near our own troops. The difficulty of fire against defiladed targets may be overcome by using reduced-velocity

Table 9-4

From	Nature of action	Radio Telephone	Remarks
Ground spotter.	Call for fire.	RIFLE this is EYEPIECE; fire mission; target number niner five zero, over.	a. Target numbers are selected from appropriate instructions contained in operation order.
Ship—	Repetition back	Fire mission, target number etc., out.	
Spotter—	Call for fire continued	Grid six niner three, five seven eight; altitude seven five meters; bearing one five hundred mils; one hundred troops in open; danger close, north west three hundred, high explosive; fuze quick; two guns main armament; adjust fire, over.	b. The spotting may be expressed in mils or degrees, from grid, magnetic, or true north. c. The altitude of the target is always included. Unit of measure is always specified. d. The target description should be brief yet clear enough to permit evaluation by the firing ship and for target intelligence. e. Proximity of friendly troops to target is sent so that the ship can provide for safe firing of the initial salvo.
Ship—	Repetition back.	Grid six niner three— etc., out.	
Ship—	Ready report.	First salvo at southeast, four hundred; ready, one three; fire, over.	Expected position of fall of shot of initial salvo always given when call for fire includes a danger situation.
Spotter—	Fire Command.	First salvo at southeast, four hundred; ready, one three; fire, over.	
Ship—	Repetition back.	Fire, out.	
Ship—	Fire report.	Shot—splash, out—	"SHOT" is transmitted upon firing. "SPLASH" is transmitted 5 seconds before salvo is due to detonate.
Spotter—	Calls the spot.	Right three hundred; drop one hundred, over.	Figure 9-11 illustrates this spot.
Ship—	Repetition	Right three hundred; drop one hundred, out.	

110.167

Table 9-4—Continued

From	Nature of action	Radio Telephone	Remarks
Ship—		Shot—splash, out.	
Spotter—		Drop one hundred, over.	
Ship—	Repetition back.	Drop one hundred, out.	
Ship—		Shot—splash, out.	
Spotter—		Left five zero; six guns four salvos; fire for effect, over.	Spotter has enclosed target 100-yard bracket. He halves the bracket, and goes to fire for effect.
Ship—	Repetition back.	Left five zero; six guns four salvos; fire for effect, out.	
Ship—		Shot—splash, out.	Made for first salvo only of fire for effect group.
Ship—		Rounds complete, over.	All fire for effect salvos have been fired.
Spotter—		Spreading fire; left one hundred; add three hundred; six guns four salvos; fire for effect, over.	Spotter wishes to distribute fire over the target area.
Ship—	Repetition back.	Spreading fire; left . . . .etc., out.	
Ship—		Shot—splash, out.	Second fire for effect salvo was fired before the first salvo was due to burst.
Ship—		Rounds complete, over.	
Spotter—		Rounds complete; end of mission; 30 troops kia; remainder dispersed, over.	Spotter is satisfied that target is neutralized. No further fire is required.
Ship—	Repetition back.	End of mission . . . etc., out.	

110.167

charges or by increasing the range to obtain a greater angle of fall.

5. Limited ammunition capacity. The limited capacity of the ship's magazines, coupled with the fact that a ship must always retain a certain amount of ammunition for its own protection, restricts the ability of any one ship to maintain uninterrupted support over an extended period of time. This disadvantage may be overcome by providing adequate ammunition replenishment and by rotating ships assigned to support missions.

SELECTION OF WEAPONS

Selection of the guns or weapons to be used in naval gunfire support is determined by the nature and size of the target to be engaged, and by the proximity of friendly troops to the target. The 5-inch gun is normally used for close supporting fire; its rapid rate of fire and relatively small pattern size make it an excellent weapon for neutralization and destruction of targets immediately in front of advancing troops. Destroyers are usually assigned close supporting-fire duties because their maneuverability permits them to shift positions easily and quickly and to take positions close inshore for direct fire on targets in coastal areas.

Eight-inch guns, with their great accuracy at long range, are normally reserved for deep supporting fire. The lethal bursting radii of projectiles from these guns limit their employment in close support. Moreover, ships mounting these guns (cruisers) are hampered in responding quickly to fire commands because they are less maneuverable than destroyers, and their fire control organization is more complex. The larger ships also have additional duties. Destructive power of large-caliber projectiles makes them particularly effective against heavy installations ashore.

Six-inch guns are suitable for either close or deep support, but the light cruisers mounting these guns are better adapted for deep support use, since their maneuverability is restricted.

Three-inch and 5-inch guns of DE's and APD's, are suitable for harassing fire missions of the sort often executed against areas remote from our own troops, such as towns, harbors, and coastal air strips. The use of these ships for this purpose provides a necessary feature of support, and releases ships with more accurate fire control equipment for use where precision fire is required.

Three-inch guns are effective for area neutralization where heavier guns are not required. They are particularly effective against shore-line targets, especially enemy personnel in caves. When such fire is controlled by the dual-purpose gun directors, it is accurate and effective at short ranges; when not so controlled, larger safety margins with respect to own troops must be allowed.

SELECTION OF PROJECTILES AND FUZES

Selection of the projectile type to be used in support of troops depends upon the type of target and the effect sought on that target. Because in shore bombardment a battery is likely to be shifted frequently and rapidly from one target to another (quite likely of different type, requiring a change in ammunition), ammunition-handling personnel should be prepared to change projectiles and fuzes on very little notice.

High-capacity (HC) projectiles are especially for use in shore bombardment. They have great explosive content (at the expense of penetrative ability) and produce a heavy blasting and fragmentation effect. HC is therefore suitable for neutralization or for destruction of relatively light installations.

Antiaircraft common (AAC) projectiles are similar to HC projectiles in explosive and penetrative qualities. Their effective bursting radius of 35 to 50 yards fits them for close-support neutralization fire.

Armor-piercing (AP) and common (COM) projectiles are designed to penetrate armor plate before detonating. Their use in shore bombardment is limited to fire on fixed enemy defenses, such as concrete pillboxes and blockhouses which cannot be reduced by HC projectiles.

Rocket assisted projectiles (RAPs) are used primarily against personnel and light-material shore targets. A secondary use is against enemy shipping at extended ranges.

White-phosphorus (WP) projectiles have been found very useful for screening, incendiary, and antipersonnel effect. They may also be used as "identifying or marker shot" to identify salvos, to permit spotting when the impact burst is invisible due to foliage, or to give a prearranged signal to the troops supported.

Illuminating (ILLUM) projectiles are used to provide illumination only.

Fuzes used with HC, AAC, and WP projectiles may be selected to meet different objectives. Mechanical time fuzes may be used to provide air bursts for maximum effect against personnel and light equipment. They should be

set to burst 25 to 50 feet directly above the target. Proximity fuzes, which require no advance setting, accomplish the same purpose with greater accuracy and less difficult fire control, as they compensate automatically for variations in ground elevation. Point-detonating fuzes also require no advance setting but produce a lower and more concentrated burst, often desirable for demolition. Base-detonating fuzes are, of course, required against armored or other heavy structures.

TARGET INTELLIGENCE

Before the undertaking of any bombardment of land targets, a thorough familiarity with the terrain and hydrographic features of the objective and with the location of profitable targets must be acquired. The study of available charts, maps, aerial photographs, radar PPI simulations, mosaics, and other pertinent information will be necessary for rapid, effective troop support. Normally these charts, maps, photographs, and target information will be furnished each fire-support ship prior to the operation. The systematic destruction of defenses requires the continuous assembly and evaluation of targets known beforehand, and of those discovered in the course of the operation. Damage assessment must be based upon visual observation and photoanalysis. A common error is over-optimism as to the effectiveness of naval fire against land targets.

PHASES OF NAVAL GUNFIRE—SUPPORT OPERATIONS

It is convenient to divide naval gunfire support for a landing operation into three general phases as follows:

1. PRELANDING BOMBARDMENT. This phase, which may commence well in advance of D-day, utilizes quick raids by surface ships to inflict damage and cause confusion, after which the ships retire. Similar strikes may be carried out by aircraft during this phase.

More often the bombardment group will move into position a few days prior to D-day and commence its schedule of prearranged fire which may continue right up to H-hour (the time of landing of the first wave of troops) or may be interrupted by retirement of the bombardment group for reasons of safety.

During this period, the effect sought by the bombardment is destruction of beach defenses, gun control and observation posts, or any defenses which could effectively oppose the landing. Slow, deliberate, close-range destructive fire is used whenever possible. In this and later phases, the identity of the actual landing beaches may be concealed by a schedule of fire covering other areas. The number of ships engaged in the prelanding bombardment, its duration, and the type of ammunition expended will depend upon such factors as the number of ships and planes available, logistics (especially ammunition supply), and the nature of the terrain and its defenses.

In addition to its primary purpose of destroying designated targets which may hamper the landing, the force may provide cover for minesweepers, underwater demolition teams, and oceanographic survey vessels. During the night it may engage in harassing fire. During the last hours prior to H-hour it may be called upon for interdiction fire to prevent assembly of reinforcements and prevent their movement into the area of the beaches to man or repair equipment. On D-day, before troops embark, bombardment of strong resistance points is intensified.

The force may also cover final minesweeping operations and the approach of the attack force, especially the transports. When transports are in position, off the landing beaches, fire can be concentrated on strong points which intelligence reports or observation indicate have not been destroyed.

During this period, air strikes are often scheduled to bomb and strafe the beaches. Provisions must be made to control fire so as to avoid hitting friendly planes.

2. SUPPORT DURING THE LANDING. The primary missions of naval gunfire in this phase are to protect the transports while the landing force is embarking in boats, to silence batteries which might destroy the assault waves as the boats move in to the beach, and to cover the actual landing of troops. The barrage must be lifted inland or shifted to the flanks as the troops near the beach to avoid hitting the landing force as well as to neutralize strong points from which destructive crossfire could rake the beaches. In addition to close supporting neutralization fire on the landing and adjacent areas, deep supporting fire must concurrently prevent enemy troop movement toward the landing area and neutralize more remote opposing enemy defenses.

During the last few minutes, as the first wave nears the beach, a final air strike often parallels

the beach, strafing and driving the enemy to cover. Because things happen so fast, and because communications with the troops being supported are rarely adequate in the critical period during and immediately following a landing, most of the supporting fire must be planned in advance, for delivery according to a carefully formulated and coordinated time schedule.

3. POSTLANDING AND TROOP ADVANCE PHASE. Naval gunfire is employed after the landing phase to assist the advance of troops to their final objectives. The postlanding fire schedule must be carefully planned for coordination with the estimated troop advance, but must be capable of quick modification to permit repeating, extending, or discontinuing any portion of the schedule when the advance differs from the plan. Close and deep supporting fire must be scheduled to continue after the landing, to neutralize enemy opposition which would hinder the rapid establishment of organized troops ashore. Scheduled fire after H-hour must last well beyond the estimated time required to establish effective naval gunfire control agencies ashore. With heavily defended objectives, scheduled fire for close support must continue at least an hour after the landing, and for deep support at least 4 hours.

Close supporting fire from ships assigned to them, daily or upon special request, is made continuously available to troop units in the assault. Troop support—including daily destructive fire missions, preparation fire for troop attacks, and night harassing fire—are scheduled for daily execution in fulfillment of troop requests. This phase of naval gunfire support begins upon completion of the prearranged scheduled fire in support of the landing, and continues until naval gunfire is no longer required for support.

PREFERRED PRACTICES IN NAVAL GUNFIRE SUPPORT

Effective support of troops by naval gunfire depends on certain operating principles and techniques of delivery—what might be called tricks of the trade, or recommended operating practice. This section briefly discusses a number of these principles and recommended techniques.

1. PREREQUISITES FOR EFFECTIVE SUPPORT FIRE. Prerequisites for effective support are proper alignment of the fire control system and gun battery, rapid and reliable internal and external communications, and well-trained ship control, fire control, and gun control personnel.

For optimum effectiveness personnel aboard a firing ship should be thoroughly familiar with the land areas the ship is assigned to cover. This can be achieved through repeated firing, observation, and analysis. Consequently, it is best to avoid shifting ships to different areas of responsibility once their personnel have become acquainted with the areas originally assigned.

2. COUNTERBATTERY FIRE. The first duty of naval gunfire in all phases of support is immediate and effective silencing of heavy enemy weapons which open fire on our forces. Hence, a counterbattery plan anticipating all contingencies must be in constant readiness, and fire-support ships must be ready and alert at all times for the delivery of this fire. If the source of enemy fire is not known, heavy counterbattery fire on suspected sources is delivered until the enemy battery is located. The whereabouts of friendly forces must be kept in mind during such an attack.

3. STEAMING SPEED. Unlike surface or air action at sea, naval gunfire support generally requires moderately low speeds. High speed in a firing ship requires it to make frequent course reversals to remain in its assigned sector, causes inaccuracies in establishing ship's position for indirect fire, takes the ship too quickly beyond effective firing positions, and may result in interference with other activities offshore. The best practice is to select a low speed which will allow good control of the ship and the supporting fire, consistent with the tactical situation and the submarine menace. If necessary, the ship may lie to or anchor, maintaining desired heading by the use of the engines. Best results for indirect fire will be obtained if ships steam on a steady course at constant low speed. However, when extensive counterbattery fire is present, the ship-speed method of gunfire support, developed during the Vietnam conflict, is used. (A description of this method is beyond the scope of this text.)

4. NEUTRALIZATION. Volume of fire required for neutralization of a target area is difficult to establish. The standard volume established before World War II prescribed the equivalent of sixteen 75-mm projectiles per minute per 100-yard square as being sufficient for neutralization. Although the experiences of World War II showed this often to be entirely inadequate, it is still a valuable guide which may be modified as conditions dictate. Experience proved that the

blast effect of bursting projectiles had been highly overrated in neutralizing effect; it was found instead that neutralization primarily depended upon the casualties produced or threatened by flying fragments. Fragmentation effects vary greatly, even in identical projectiles, because they depend on such factors as angle of fall and terminal velocity. For example, the number of casualties may double with an increase in angle of fall from 10° to 60°. Effectiveness of fire for neutralization will also vary with terrain, types of enemy installations, and quality of enemy troops.

5. USE OF ILLUMINATING PROJECTILES (star shells). Illumination of land areas by naval star shells is effective in preventing enemy counterattacks, infiltration, and the movement of enemy troops at night. Its morale-boosting effect on our own troops generally results in requests for exorbitant star-shell expenditures to produce unnecessary illumination of the land area throughout the night. Except during actual enemy counterattacks, star shells fired at a reduced rate and at irregular intervals normally discourage enemy movement. Maximum benefit from the limited supply of star shells available requires judicious control and coordination by troop units to avoid the silhouetting of own forces ashore and afloat. When delivering illumination fire, the line of fire must be so adjusted with relation to our front lines that friendly troops are not endangered by star-shell bodies. Searchlight illumination for troop support is generally unsuccessful; it almost invariably draws enemy fire on the ship employing it.

6. RECOMMENDED PRACTICES IN FIRING. Use direct fire whenever possible. Indirect fire requires more ammunition and time than direct fire for equal destructive success. Indirect fire requires air or ground observation of the fall of shot in order to ensure hits on point targets; this is not essential for direct fire. The effectiveness of naval gunfire is increased by the employment of an air spotter working with a ground spotter.

Once established, maintenance of the hitting gun range and deflection is essential to effective destructive fire. Periods of continuous slow fire with reduced salvos are therefore preferable to more rapid fire interspersed with relatively long nonfiring intervals.

For decisive destruction of heavy defenses, use, if at all possible, very close-range, slow, deliberate, direct fire. Fire-support ships should usually operate as close inshore as safe navigation, the tactical situation, enemy shore batteries, and the type of fire required will permit.

When close supporting neutralization fire on the landing area in support of troops about to land is scheduled to be shifted on a time basis relative to the estimated time of H-hour, it must be adjusted according to the actual position of the troop landing craft. From reports of landing-craft progress received, but primarily from own observation when possible, fire-support ships must individually determine when their fire is about to endanger troops nearing shore, and accordingly shift the fire from the landing area.

Close cooperation between ships and the troop units assigned for support is essential for information between supporting ships and troop units can ensure intelligent and effective fire support. Of particular importance is the safety requirement that all fire-support ships maintain an up-to-date plot of own troop frontline positions as periodically announced by landing force elements. This not only prevents endangering own troops, but permits selection of the most suitable line of fire with respect to troop lines, and safeguards friendly aircraft operating in the area.

Specific information on all phases of gunfire support in amphibious operations may be found in NWIP 22-2 (latest revision).

CHAPTER 10

AIRCRAFT ARMAMENT

In this chapter, we discuss rockets and their launchers, bombs, and guns used on naval aircraft. Guided missiles are covered in Naval Missile Systems, NavPers 10785 series.

ROCKETS

The use of rockets in warfare is not a recent development; in the thirteenth century they were used by the Chinese in the defense of Peiping against the Mongols. During the first two decades of the nineteenth century an Englishman, Sir William Congreve, developed artillery rockets that weighed up to 24 pounds. The rockets had a range of about 2 miles and were used by the British during the Napoleonic Wars and, in the history of our own country, during the attack of Fort McHenry in the War of 1812.

The revolutionary gun designs later in the nineteenth century, along with the development of smokeless powder, partially eclipsed the further development of rockets as a military weapon until World War II. During World War I, for example, rockets were largely restricted to such auxiliary jobs as signaling, and carrying lines in sea-rescue work. Their only aerial offensive use consisted of tying them to the struts of French and Russian aircraft and shooting them into German observation balloons.

Beginning in the latter part of 1941, the armed forces of Germany, Great Britain, and Russia came out with military applications of the rocket principle. These countries had been working on military rockets for several years before the outbreak of World War II.

Rockets were still much less accurate than guns, but they made up for this shortcoming by the fact that they had no recoil and could be fired from a simple light launcher instead of a heavy gun. They could be used where absence of weight was desirable or a great volume of fire was more important than accuracy. Short-range rockets were developed for use against shore installations, ships, tanks, aircraft, and personnel. The Germans produced a long-range rocket missile known as the V-2.

By 1941 the United States also had embarked on a rocket program, and began rocket operations in the North African campaign of World War II with the Rocket Launcher M1, popularly known as the bazooka. The year 1943 ushered in the first aircraft rockets; and by the end of the war, a variety of aircraft rockets were in combat use. The rockets to be discussed in this chapter are the present day descendants of these pioneers.

A rocket is a missile propelled by reaction thrust produced by the escape of gases evolved from the burning of self-contained solid, liquid, or gaseous propellants. A true rocket by definition does not, for example, use atmospheric oxygen to burn its fuel.

In general usage, any missile that is rocket propelled can properly be called a rocket. In naval ordnance terminology, however, the unqualified term "rocket" denotes a rocket-propelled missile that is not guided after launching, either by built-in equipment or by command signals from without. Rocket-propelled missiles that are guided after launching are guided missiles, and are covered in Principles of Guided Missiles and Nuclear Weapons, NavPers 10784 series.

Rocket propulsion has two noteworthy characteristics:

1. The propulsion force delivered is independent of atmospheric air, and thus the rocket may be propelled through empty space.
2. The propulsive force is unaffected by the rockets velocity.

PRINCIPLE OF ROCKET PROPULSION

A rocket motor is a metal tube that serves as a combustion chamber. The burning propellant generates hot gas, and the gas pressure within the combustion chamber rises quickly to some

value determined by the amount and characteristics of the propellant and the size and shape of the nozzle (or nozzles). The gas exerts approximately the same outward pressure on each square inch of surface within the combustion chamber; however, the gas rushes out of the nozzle without exerting any force upon the area of the opening, but with exertion of full force upon the corresponding area at the forward end of the combustion. Thus a net force or thrust acts in the forward direction.

A rocket motor is called a reaction motor because its operation is based on Newton's third law of motion: To every action (force) there is an equal and opposite reaction (force). Simply stated, the rocket's propelling force is the reaction of a force acting in the opposite direction.

The conversion of heat energy into kinetic energy is fundamental to rocket propulsion. This poses two basic problems: (1) to generate gas under high pressure and at a constant rate—a problem of chemical reaction; and (2) to direct the high-pressure gases into a high-velocity stream—a problem of nozzle design. Pressure in a rocket motor depends largely on burning rate and escape rate. In solid-fuel rockets, for example, the composition of powder, shape of grain, and rate of burning, which have important relationships to performance as discussed in chapter 4, are also important factors in rocket design.

ROCKET CHARACTERISTICS

The principal factors taken into account in designing a rocket are hitting accuracy, payload weight in relation to overall weight, velocity, time-to-target, type of target, and safety. Many of these factors contend against each other. The guiding factor is the tactical purpose of the rocket.

Lack of recoil is a major advantage of rockets. The force of the propelling gases acts only upon the motor walls. Except for the impinging jet exhaust, no stress is exerted upon the launcher and firing aircraft. Therefore, the launcher may be a relatively simple, light structure.

The rocket carries its propelling forces within it, and a prolonged time of acceleration is possible. This factor eliminates the need for high initial acceleration to attain required velocity. The acceleration given a shell may be approximately 100 times greater than that given a rocket of comparable caliber. Therefore, rocket components may be of relatively light construction.

The mean dispersion of a salvo of air-launched rockets is about 10 to 20 mils (10 to 20 feet at a 1,000-foot range). This shotgun effect provides high hit probability. Rocket accuracy is comparable to that of a gun on a fixed mount and superior to that of a bomb. This degree of accuracy is all that rockets need. Each rocket carries enough high explosives to destroy the target for which it has been designed.

Modern combat requires the greatest destruction deliverable in the shortest possible time. In this situation, the superiority of rockets over other weapons is decisive.

Characteristics of Trajectory

The trajectory of a rocket differs from that of other projectiles, because a rocket carries its source of power with it. The motor not only increases the size of the missile in relation to its payload but also provides reduced initial velocity, prolonged period of thrust, and increased range potential.

A pilot's personal flying habits are critical to the successful firing of rockets. He must master the aircraft as a launching platform since the rocket trajectory is an extension of his aircraft trajectory and, as such, is sensitive to every variation during the tracking run.

In order to aim successfully at the target, it must be possible to predict the rocket trajectory. The exterior ballistic characteristics of rockets are known, and the trajectory of a rocket launched by an aircraft in unaccelerated flight is relatively simple to predict. The directing forces acting upon the rocket converge in a vertical plane, directing the rocket forward and downward. A skid, however, introduces horizontal influences which destroy this vertical unity, and the trajectory becomes relatively unpredictable. Although the rocket follows the flight path of the aircraft at the instant of release, slight variations of the aircraft will not seriously affect rocket trajectory.

Launching Characteristics

The accuracy of a ground-launched rocket is affected by the launcher length. The launcher has to be of sufficient length to allow the rocket to build up a velocity that will insure stability. The initial velocity of an aircraft-fired rocket is nearly the velocity of the aircraft; therefore, aircraft rocket launchers may be very short in length with no adverse effect upon accuracy.

The effective launching of a rocket in the direction of the flight line may be upset by local air turbulence which acts to increase dispersion. However, the impact of the windstream along the

flight path tends to correct this yaw. The possible effect of local airflow is considered in the aircraft design.

The following factors affect the placement of launchers upon the aircraft:

1. The effect of turbulent air currents about the launcher upon the initial rocket trajectory.
2. The effect of the jet blast of the rocket upon the launcher and aircraft structures and engines.

ROCKET MOTOR DESIGN

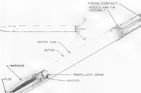
Figure 10-1 shows the external appearance of one common type of rocket. The head contains a high-explosive charge and a nose fuze to initiate detonation. The motor contains the combustion chamber, and houses the propellant charge. Hot gases from the combustion chamber issue from a nozzle at the after end of the assembly.

The thrust of a rocket motor is, as already stated, an equal and opposite reaction to the thrust developed by the expansion of gases discharged at the nozzle. Since the expansion of gases is maximum in a vacuum, that is where rockets function most efficiently. Rocket motors contain all the essentials for functioning, and do not require atmospheric oxygen for combustion.

The important functional parts of a rocket motor (in the types of rocket discussed in this chapter) are the nozzle, the motor tube, the propellant with its igniter, and the stabilizing features.

Nozzle

The function of the nozzle (of which there are usually several) is to permit the hot gas produced



110.142
Figure 10-1. — Typical airborne rocket.

by the burning ballistite propellant to flow out of the rocket motor, pushing the rocket along as it goes.

For maximum efficiency in developing thrust, gas flow must be non-turbulent. The shape of the nozzle (fig. 10-3) determines the characteristics of gas flow, and hence has much to do with how efficiently the gas flow propels the rocket. For a smooth, controlled trajectory, the nozzle must produce thrust along the long axis of the rocket; and the nozzle must be designed to develop every possible bit of thrust from the flow.

By tapering the rear of the chamber so that it narrows smoothly toward the nozzle aperture, a smooth, non-turbulent flow of escaping gas is created. This tapered section forms the forward half of the nozzle. The tapered extension, forming the after end of the nozzle which leads outward from the nozzle aperture, forces the escaping gas as it expands to furnish additional (about 33 percent) forward thrust.

Motor Tubes

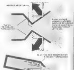
The rocket motor tube contains the propellant charge and igniter. It is a combustion chamber in which the propellant is burned to provide the motive power (hot gases) for the rocket. It generally threads to the rocket or an adapter in the base of the head, and is usually shipped separate from the head. The diameter of motor and warhead is the same.

Propellants

Although a rocket may be propelled by either solid or liquid fuel, airborne rockets utilize only solid propellants. The propellant used is a single-grain, double-based type, consisting of either ballistite or SPCG. The grain is extruded into a perforated star shape (cylindrical with an eight-point star-shaped hole through the center) as shown in figure 10-3.

A salt-coated ballistic rod is suspended in the center of the propellant grain to smooth the burning and suppress the flash, which aids in preventing flameout of the aircraft jet engine.

Inhibitors are designed to restrict or control the flame propagation on the propellant surface. The end inhibitors are molded plastic components bonded directly to the end of the propellant grain. The external surface inhibitor is spirally wrapped ethyl cellulose tape bonded to the propellant surface.

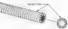


53.186
Figure 10-3. — Features of rocket motor nozzle design (schematic).

PROPELLANT CHARACTERISTICS. — The burning in a solid propellant grain proceeds inward from all ignited surfaces, at a rate determined by the pressure in the motor tube and the temperature of the grain, until most of the propellant is consumed.

Propellant grains burn from about 0.15 to 1.5 seconds, depending on their size, temperature, burning area, and shape. Rate of burning varies directly with initial temperature of the grain. The final velocity attained by two rockets of the same type and launched under the same conditions, except for different propellant temperatures at time of ignition, will be practically the same. However, a rocket launched at 100° F will have attained its peak velocity before the one launched at 40° F. The difference in time required to reach peak velocity will make a difference of a few mils deflection in the trajectories of the two rockets.

Very high propellant temperatures cause such a rapid rate of burning and high pressure that the motor tube may rupture. Very low temperatures cause the grain to burn unevenly, so that spurts of gas called "chuffing" are emitted from the



110.142
Figure 10-3. — Propellant grain.

nozzles or the grain disintegrate, emitting burning slivers of ballistite. When so fired, the rocket will travel only a short distance.

The firing of some rockets is limited to a relatively narrow temperature range compared to that suitable for the firing of guns. The present upper limit for these rockets is about 165° F; the lower limit about -65° F.

Igniter

The igniter which sets fire to the propellant grain (fig. 10-4), is located in the forward section of the motor tube adjacent to the grain. It consists of a small container of black powder, an electric impulse heats an electrical filament in the squib which ignites the black powder. This ignition provides just sufficient energy to ignite the propellant without producing undue stress on it.

The igniter is designed to give a response in minimum time with a squib current of 1 ampere or more although as small a current as 0.2 ampere will set off the black powder after a short delay. The nominal resistance of the squib is 1.0 ohm. Therefore, ignoring any line resistance, an emf (electromotive force) of 0.2 volt is sufficient to set off the charge, and 0.75 volt gives satisfactory performance.

The firing impulse is transmitted to the igniter by either a contact disk or a contact band.

The contact disk (fig. 10-5A), which is used with tubular launchers, provides the electrical contact for one of the two igniter leads. The other igniter lead is grounded to the nozzle plate which is electrically connected to the grounded voltage source through the launcher. When the rocket is placed in the launcher, the contact disk is automatically in contact with an electrical terminal which transmits the firing impulse to the rocket.

The contact band (fig. 10-5B), on the forward end of the motor, is covered by a shielding band that must be left in place until just before the

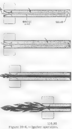


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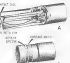
Figure 10-4. — Igniter operation.

contact band enters the launcher during loading. The shielding band seats in the motor-detent groove and covers the ignition contact band, thereby shorting out the ignition circuit and providing protection against radiofrequency (RF) energy.

Stabilizing Features

A rocket with its center of gravity forward of the nozzle is inherently unstable. If the propellant gas stream develops momentarily an off-center thrust component, or if the rocket as a whole is deflected momentarily by some such accidental cause as a gust of wind, the rocket is likely to



110.144
Figure 10-6. — Electrical leads.

veer or even tumble. To prevent these erratic movements, some form of stabilization must be applied. The classical 18th-century war rocket and its modern Fourth of July descendant used a stick protruding behind the rocket to stabilize it by moving its center of gravity aft. Modern war rockets are stabilized by fins.

Fins provide rocket stability by the action of biting into the windstream, increasing the aerodynamic forces at the rear of the rocket in relation to those at the nose, and causing the center of pressure to shift to the rear. When a rocket yaws, the longitudinal axis of the rocket deviates from its flight path, and the pressure of wind upon the fins exerts a restoring moment which tends to keep the nose directed at the point of aim.

Four or more fins symmetrically fixed at the rear of the rocket comprise the fixed-fin assembly. Fixed fins have the advantages of rigidity and ease of manufacture, but when the size of a rocket is critical, fixed fins are a disadvantage. They extend the diameter of the round, thus limiting the number which may be carried on a given launcher. At the present time, only rocket motors used with guided missiles are stabilized with fixed fin assemblies.

Folding fins (fig. 10-6) are usually hinged in such a manner as to maintain the nominal diameter when in the launcher. Use of folding fins increases the number of rounds that can be carried and the number which may be fired from a given frontal area.

ROCKET WARHEAD DESIGN

Different tactical requirements demand specific types of rocket warheads to be used with airborne rockets. These warheads are broadly classified as high-explosive (HE), smoke, flare, and practice.

High-Explosive Warheads

High-explosive warheads contain some type of HE material surrounded by a metal case. Within this category are several types of heads, each designed for specific types of targets. These warheads may be divided into the following types (fig. 10-7):

1. HE antitank/antipersonnel (HEAT/APERS).
2. HE fragmentation.
3. HE general purpose (GP).
4. HE antitank (HEAT).

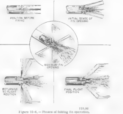
ANTITANK/ANTIPERSONNEL WARHEADS.— The HEAT/APERS warhead (fig. 10-7A) combines the effectiveness of the fragmentation and antitank warheads.

The explosive charge in this type of warhead is detonated at its after end to produce the jet from the cone at the forward end. Detonation by the booster usually is accomplished through transmittal of the explosive impulse by a length of detonating cord that connects the booster charge to the initiating charge, which is adjacent to the nose fuze. The combination of an instantaneous-acting nose fuze and rapid-burning detonating cord permits detonation of the explosive load in time for the shaped charge to produce its explosive jet before being disintegrated by impact on the target.

The warhead in figure 10-7A is fuzed with a proximity fuze.

FRAGMENTATION WARHEADS.—Fragmentation warheads (fig. 10-7B) are effective against personnel and light material targets such as trucks, parked aircraft, etc. The warhead explosive is detonated by either a point detonating or proximity fuze. Upon detonation, the case breaks up into a large quantity of metal fragments that spray the area at a high velocity and cause considerable damage.

GENERAL PURPOSE WARHEADS.—The general purpose (GP) warhead (fig. 10-7C) is a



110.96
Figure 10-6. — Phases of folding fin operation.

compromise between the armor-piercing and the fragmentation designs. Its warhead has a nose section and walls not as strong as those of an armor-piercing warhead, yet stronger than those of a fragmentation warhead. The explosive charge is less than that in the high-explosive antitank warhead.

The GP warhead is for use against a variety of targets. Its maximum penetration may be obtained by using a solid nose plug and a delayed-action base fuze. Its maximum blast effect may be obtained by using an instantaneous-acting nose fuze.

ANTITANK WARHEADS. — The HEAT warhead (fig. 10-7D), developed for use against tanks but equally effective against other armored or fortified targets, employs the shaped-charge principle of explosives to produce a jet of high-velocity, high-temperature particles.

The explosive jet will penetrate heavy armor (or concrete) but will not produce an explosive blast. The jet will materially increase the temperature behind the armor and, in case of a small enclosure such as the inside of a tank, its searing heat normally will kill the occupants.

Smoke Warheads

Smoke warheads (fig. 10-8) are designed to produce a volume of heavy smoke for target marking. The warhead contains a burster tube of explosive, usually composition B, which bursts the warhead's walls, dispersing the smoke. These warheads are designated SMOKE, followed by the abbreviation for the smoke producing agent in

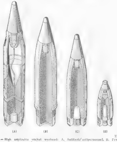


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Figure 10-7. — High explosive rocket warhead: A. Antitank/antipersonnel. B. Fragmentation. C. General purpose. D. Antitank.

contains; for example, WP for white phosphorus or PWP for plasticized white phosphorus.

Flare Warheads

Flare warheads (fig. 10-9), designed to provide illumination for tactical operations, consist basically of a delay action fuze, illuminating candle, and parachute assembly. Approximately 15 seconds after the rocket is fired from the launching aircraft, the fuze simultaneously ignites the expelling charge and ignition composition. The expelling charge generates gas pressure sufficient to separate the outer case from the aluminum base and to shoot it forward, leaving the two inner cases containing the candle and parachute assembly unsupported so that the windstream forces them away from the base. As the rocket continues in its flight, it exerts a pull on an after cable assembly which strips off the deployment bag, allowing the parachute to open and suspend the burning candle.

Practice Warheads

Practice warheads (fig. 10-10) are either dummy or inert-loaded service warheads in which

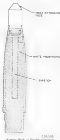

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Figure 10-8. — Smoke warhead.

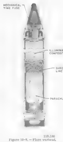

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Figure 10-9. — Flare warhead.

the weight and placement of an inert filler (such as sand) gives the practice warhead the same ballistic characteristics as those of the explosive-loaded service warhead. A steel nose plug is assembled in the practice heads in place of the nose fuze. Inert loaded heads do not require fuze cavity liners, although some do have them.

ROCKET FUZES

Rocket fuzes are classified primarily according to their location in the warhead: nose fuze or base fuze. They may be further classified by mode of operation, such as impact firing, mechanical time, or proximity.

Impact firing fuzes are those that function when the rocket strikes a target that offers sufficient resistance to cause crushing or other disarrangement of actuating parts. These fuzes may be located in the nose of the warhead, in which case they are called point detonating fuzes (PDF), or located in the base of the warhead and called base detonating fuzes (BDF). Nose and base fuzes are designed to function either instantaneously or after a short delay that affords the

110.147
Figure 10-10. — Typical practice warhead.

warhead time to penetrate the target before functioning. A typical nose point detonating fuze is illustrated in figure 10-11.

One mechanical time fuze is now available for rocket application. It is designed to sense acceleration, and after a set distance to start a nonsettable mechanical timer. At the end of a set elapsed time the fuze initiates the firing train.

Proximity (VT) fuzes are those wherein initiation occurs by sensing—usually by electronic means—the presence, distance, and/or direction of the target.

In general, fuzes contain devices to prevent detonation due to normal transporting, handling, assembling, and launching of the complete rocket. The fuze also is detonator-safe. This means that the explosive train of the fuze is interrupted so that, if the detonator is prematurely initiated while the fuze is unarmed, the booster of the fuze and the explosive filler of the warhead will not be detonated.

In some fuzes, the detonator-safe requirement is accomplished by keeping the detonator out of line with the booster when the fuze is in an unarmed position. In other fuzes, the flash from the detonator is blocked. Arming of a fuze is accomplished by aligning the detonator and booster or opening of the flash path.

AIRBORNE ROCKETS

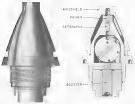
Airborne rockets, consisting of fuzes, warheads, and motors, are combined and assembled in various configurations to meet specific tactical requirements. For example, a rocket assembly consisting of a fragmentation warhead armed with a proximity fuze would be entirely unsuitable for use against an armored tank or bunker. Likewise, the HEAT warhead fuzed with the base fuze would be relatively ineffective against personnel or unarmored targets. With each specific type of target, the right combination of warhead, fuze, and motor can be assembled from the wide variety of available components.

Aircraft rockets are used primarily as forward firing weapons, which supplement or take the place of forward-firing guns. The virtual absence of recoil in launching aircraft rockets makes possible the use of lightweight gear for such launching, and introduces no stresses inimical to the plane's structures. A modern rocket-firing plane armed with 5.0-inch rockets can deliver one salvo comparable to that of a destroyer. In making such a comparison, however, it must be remembered that the ships can keep on firing, whereas the planes must return to base after delivering their payloads. Generally speaking, rockets provide superior firepower with minimum added weight. The payload of a rocket is less than that of a comparable bomb, but the rocket presents advantages related to accuracy of fire and greater penetration.

2.75-Inch Folding Fin Airborne Rocket (FFAR)

The 2.75-inch FFAR (fig. 10-12) has proved to be an effective weapon against targets such as locomotives, convoys, buildings and bunkers. With the use of the Mk 5 HEAT warhead, the rocket has also demonstrated considerable destructive capabilities against tanks and other armored vehicles.

The 2.75-inch FFAR is designed to be fired in large numbers to produce a shotgun type pattern. Thus, it is carried and launched from packages



110.148
Figure 10-11. — Typical point detonating fuze.

(pods) containing 7 or 19 rounds. (These are described later in this chapter.)

5.00-inch High-Velocity Airborne Rocket (HVAR)

The HVAR or Zuni (fig. 10-13) is a 5.00-inch, folding fin, high velocity, solid-propellant rocket designed for use by fighter and attack aircraft against ground targets.

Like the FFAR, the Zuni may be assembled in various warhead and fuze combinations. In addition to those combinations authorized for the 2.75-inch, the Zuni may be assembled in variations such as the proximity/fragmentation fuze warhead combination, or in the mechanical time/flare fuze and warhead combination.

Rocket Launchers

Airborne rocket launcher packages are aluminum cylinders containing horizontally nested tubes, and are used exclusively with folding-fin aircraft rockets. The design permits multiple loading and launching of the 2.75-inch FFAR and the 5.00-inch HVAR. Aircraft rocket launcher packages provide a means by which rocket motors (and, in some cases, completely assembled rounds) may use the same containers from manufacture to firing.

Frangible paper fairings are used in conjunction with launcher packages. These fairings are attached to both ends of the launcher prior to flight to provide low-drag aerodynamic characteristics. During firing, the fairings are disintegrated by rocket blast and by the forward movement of the rockets.

In most cases, launcher packages are jettisoned after firing, at the pilot's discretion.

2.75-INCH ROCKET LAUNCHER PACKAGES. — The 2.75-inch launcher packages differ

110.98.1
Figure 10-12. —2.75-inch FFAR.

in capacity, firing capability, and physical dimensions. Those in current use contain either 7 or 19 complete rocket assemblies.

Launchers are shipped with all components assembled. To ready launchers for flight requires only removing shipping hardware and installing the fairings.

The airborne configuration (fig. 10-14) consists basically of three sections—the forward fairing, the center section, and the after fairing.

The fairings fit flush with the outside surface of the center section to form an aerodynamically smooth joint. The forward fairing consists of a one-piece impregnated molded fiber section with an attached metal locking band. The center section contains the suspension system, all electrical circuits, launching tubes with detents, rockets, and the intervalometer. The aft fairing is a one-piece unit assembly similar to the forward fairing but constructed differently because of the function it performs. The rocket blast shatters the nose portion, while the base section remains on the launcher and acts as a choke or funnel to direct debris away from the aircraft.

When the firing switch in the aircraft is closed, electrical power is applied to the system as shown in figure 10-15. Also shown is the firing order of the rockets as they leave the launcher. The firing sequence is 1A, 1B, 2A, 2B, etc. Rocket number 10 is fired last. The firing switch must be closed for at least one-sixth of a second or a failure to fire may result.

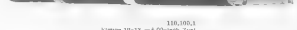
The heart of the rocket launcher is a shaft-fixed intervalometer. Electrical power required to operate the intervalometer and ignition system is supplied to the intervalometer by the aircraft's 28-volt d-c armament circuit. The wiring of the intervalometer converts the firing pulse into ripple-firing with a 10-millisecond delay interval between each firing pulse.

5.00-INCH ROCKET LAUNCHER PACKAGES. —The Zuni rocket launcher package (fig. 10-16) is a reusable dual-purpose pod which houses four 5.00-inch motors from the time of manufacture until assembled with warheads and fired at the target.

The flight configuration consists of a launcher center section, with the shock pan, cover, and lockring assemblies removed, containing four assembled Zuni rockets and a frangible fairing installed and securely locked in place on each end.

The launcher center section contains the four launching tubes, electrical ignition system, suspension lugs, and a sear type detent latch.

Electrical power for the rocket ignition system is supplied to the launcher by the 28-volt d-c armament circuit of the aircraft. Electrical connection between the aircraft and the launcher



110.100.1
Figure 10-13. —5.00-inch Zuni.

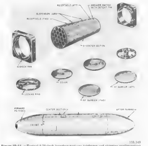


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Figure 10-14. — Typical 2.75-inch launcher package (airborne and shipping configuration).

is made through either of two paralleled receptacle assemblies, located in the vicinity of the launcher center section lugs. As a safety requirement, both receptacles are fitted with shorting plugs and dust caps. A selector switch is located in the after bulkhead of the launcher for preflight selection of either ripple- or single-firing of the rockets. A rotary relay type intervalometer located in the forward bulkhead distributes the firing pulse to the individual rockets and is designed for a 50-millisecond time-delay interval. Electrical connection to the rocket motor is completed in each tube through contact posts on the detent latch to a contact band on the rocket motor.

Rocket Safety Precautions

The airborne rocket is no more dangerous than any other explosive weapon, but it does have certain peculiar hazards. A completely assembled rocket, if accidentally fired, will take off under its own power in the direction in which it is pointed, with threat of damage to anything in its path. When fired, an assembled rocket expels a blast of burning gas capable of injuring or

110.150
Figure 10-15.—Rocket launcher firing circuit, simplified schematic.

killing anyone it strikes because of concussion or burns.

The following hazards exist in dealing with aircraft rockets:

1. Inadvertent electrical contacts which may set off the rocket.

2. Excessive temperatures or pressures which may cause the motor to explode in a ground fire or in the air when fired.

3. Continued exposure to abnormal stowage temperatures which may cause the propellant to deteriorate, with attendant hazards of possible explosion when the rocket is fired.

4. Rough handling or blows which may break the propellant grain, thus exposing too much surface to burning and leading to possible excessive pressures in the motor when fired.

Generally, a rocket motor without a head attached is unlikely to explode. It does present a potent fire hazard since ballistite or SPCG ignites easily and burns readily. High-explosive heads, either fuzed or unfuzed, present the same risk as do gun projectiles under the same conditions. Rocket, whether completely assembled or disassembled, must be handled with extreme care to avoid damage to parts.

Rocket motors should be stowed in the same manner as smokeless powder. Matches and open flames must never be allowed in the stowage area. Smoking should not be permitted in the loading area within 200 feet of any ammunition.

Rocket motors are not to be fired when the propellant's temperature is outside the safe-firing temperature limits specified on the motor tube. If the motor has been exposed for more than 1 hour to temperatures outside these limits, the motor is to be maintained within the safe-temperature limits for 6 hours before firing.

Rocket motors must not be stowed in the same compartments with or near apparatus or antenna leads, due to the possibility of induced currents igniting the motor.

High-explosive heads and fuzes (except base fuzes which are permanently installed in the head) must be stowed separately from each other, in the same manner as high-explosive projectiles.

Rocket fuzes shipped in sealed containers are to remain in the sealed cans during stowage. As a rule, nose fuzes are stowed in a ship's bomb fuze magazine, or under conditions specified by the Naval Ordnance Systems Command. Cans should be placed upright in assigned magazines and secured firmly.

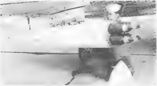
Fuzes are relatively sensitive and must be handled with care to avoid extreme shocks which might cause damage. Operations such as fuzing, unfuzing, assembly, or disassembly of all types of ammunition should be carried on at a distance from other explosives and from vital installations. Only the minimum number of persons and rounds required should be in the vicinity. The ideal situation would be to permit work on only one round at a time, on a deck or at some other location remote from all magazines, ready stowage, explosive supplies, or vital installations.

Examination of the exterior of some fuzes does not indicate whether they are armed. If for any reason it is thought a fuze might be armed, it should be treated as an armed and sensitive fuze. No attempt should be made to remove it from the rocket head. The complete fuzed round should be disposed of by gently lowering it tailfirst into deep water. If available, explosive ordnance disposal personnel should dispose of such rounds.

Disassembly of rocket fuzes is not permitted except as authorized by the Naval Ordnance Systems Command.

AIRCRAFT BOMBS

Aircraft bombs are weapons designed to be dropped upon enemy targets to reduce and neutralize their war potential by destructive explosion, fire, or nuclear reaction. They are used strategically to destroy installations, armament, and personnel, and tactically to provide direct support of our land and sea forces engaged in offensive or defensive operations. Bombs are procured



110.100.2
Figure 10-16. — Zuni (LAU-10A/A) rocket launcher.

both by the Navy and the Air Force, and are used in common by the two services.

This chapter does not take up nuclear bombs. These weapons are discussed in the second volume of this series.

A bomb usually consists of a body, stabilizer, and means of detonation. The body can be filled with either an explosive, chemical, nuclear, or inert filler. Stabilizers attached to the after end of the bomb body consist of sheet metal fabrications.

The efficient destruction of various types of enemy targets requires different types of bombs; these are generally classified according to their filler i.e., high explosive, chemical, napalm, inert, etc.

EXPLOSIVE AND OTHER CONTENTS OF BOMBS

A fundamental characteristic required of the explosive charge of a bomb is relative insensitivity to ordinary shock and heat incident to loading, transporting, handling, and storing. This insensitivity permits:

1. Adequate safety for the using personnel (when the explosives are handled properly).
2. Maximum target damage by control of the bomb's detonation.
3. Jettisoning bombs from aircraft without exploding, in emergency.

It is evident that these requirements, as with gun projectiles and other explosive devices, make it necessary to use an explosive train in aircraft bombs. In most bombs, the train begins with a detonator containing a small amount of very sensitive explosive. (The detonator is part of the bomb's fuze.) The detonator sets off a rather less sensitive booster; in turn the booster explodes the main charge.

In addition to the different types of explosives required in the individual components of the explosive train of any single bomb, the main charge of any bomb is made up of different explosives, depending on the purpose of the bomb. High explosives used in present types of bombs include TNT, Tritonal, HBX, and H-6. Chemical

agents are chiefly blister gases (vesicants) such as mustard, choking gases such as phosgene (CG), and the blood and nerve gases, hydrocyanic acid (AC). Fire bombs use a mixture of napalm powder and aviation fuel. Practice bombs may be filled with either sand, water, or plaster.

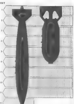
BOMB CONFIGURATION

Aircraft bombs used during World War II and shortly thereafter were designed primarily to provide space for as much bursting charge or other payload as possible without compromising simplicity of manufacture or satisfactory streamlining. This approach resulted in a gratifyingly efficient container whose silhouette was short, compact, and stubby (as can be seen in figure 10-17), economical of bomb bay space, and aerodynamically efficient enough to make the bomb ballistically reliable (i.e., when released from an aircraft under a given set of conditions, it could be depended upon always to land in the same locality).

For subsonic aircraft, this constituted satisfactory performance. But when the speed of bombardment aircraft exceeded that of sound, the hitherto satisfactory bomb shape was found to be poorly adapted to the new conditions either when the bomb was slung under the aircraft's wing or fuselage, or when it was released. Not only was the bomb now a serious detractor from aircraft performance (if carried outside the fuselage), but it could no longer be dropped as accurately. Besides, the mechanical arming wire arrangement used to control bomb fuze arming was apt to tear loose or foul the bomb or parts of the aircraft, causing the bomb either to become a dud or to arm prematurely and become a menace to the aircraft carrying it.

It then became necessary to redesign the aircraft bomb so that it would be satisfactorily streamlined at sonic and supersonic speeds, and so that its fuze's arming could be reliably controlled without danger of its vital parts being damaged by high air speeds. To solve the first problem, the bomb's exterior shape was altered to give it minimum drag at high speed. To solve the second, an internal electrical fuze control system was substituted for the conventional mechanical system.

Figure 10-17 compares the silhouette of a 1,000-pound conventionally-shaped bomb (on the right) with that of a low-drag bomb of the same weight (on the left). The flat forward end on the low-drag bomb indicates that it is set up for a mechanical fuze arrangement. A low-drag bomb



3.119
Figure 10-17. —Silhouettes of a low-drag bomb (left) and a conventional bomb (right).

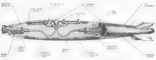
set up for electric fuzing has a smoothly streamlined nose that comes to a point.

BOMB COMPONENT NOMENCLATURE

A COMPLETE ROUND denotes a bomb with all its components as it is suspended from the rack or shackle of the aircraft ready for flight. Some of the major components of bombs are listed below and illustrated in figure 10-18.

BOMB BODY. The bomb body is the container that holds the filler.

FIN ASSEMBLY. The fin assembly is the flight stabilizer of the bomb and usually is made of sheet metal. In newer types of bombs, a conical fin assembly with better aerodynamic properties is used.



110.151
Figure 10-18.—Typical aircraft bomb, cutaway view.

FUZE. Fuzes initiate bomb detonation. They contain sensitive explosives and should be handled carefully.

ARMING WIRE ASSEMBLY. This consists of either a single or double wire attached to a swivel loop, and is used to keep the fuzes safe prior to release of the bomb from the aircraft.

SUSPENSION LUGS. Suspension lugs are screwed into the bomb body either 14 or 30 inches apart, depending upon the size of the bomb.

HOISTING LUGS. These lugs are screwed into the bomb body usually between the suspension lugs, and are used to handle and hoist the bomb.

FILLER. The type of filler depends upon the prospective use of the bomb. The filler charge in high-explosive bombs is usually cast (melted) loaded with the explosive material mentioned earlier.

ADAPTER BOOSTERS. Adapter boosters are explosive loaded bushings threaded on the outside for insertion into the bomb body, and threaded on the inside to receive the fuze. Current general purpose bombs require adapter boosters in the nose and tail when using mechanical fuzes.

CHARGING TUBES. Charging tubes are conduits placed inside the bomb before the explosive charge is loaded. These tubes contain the circuitry which connects the electrical fuzes to the aircraft charging gear.

MARKING AND IDENTIFICATION

Bombs and bomb components are completely identified by standard nomenclature and ammunition lot numbers stamped on all packings as well as on the item itself. Items of Navy design are designated by the word Mark or its abbreviation (Mk) followed by a numeral. Modifications of the original design are indicated by the term "Mod" and followed by a numeral.

Items of Army or Air Force design consist of the letter "M" followed by a numeral. Modifications to the original design are indicated by the letter "A" and the appropriate numeral added to the model designation.

Certain items have been standardized for use by all services. The model designation of such an item is prefixed by the letters "AN".

The designations T1, T2, etc., indicate a developmental item. While in the development stage, and when a major change is incorporated, the item will take a designation such as T1E1 or T1E2. Such a designation indicates a change affecting military characteristics or installation.

Bombs are painted in various color schemes as a ready means of identification. Color bands, depending upon their color, size, and location, indicate the type of bomb and the type of explosive filler used. Identification markings and the bomb's color provide further identification of it. The color coding system for bombs is described in the sections concerning each type of bomb.

CLASSIFICATION OF BOMBS

Aircraft bombs are classified according to filler as follows:

1. High explosive.
2. Fire.
3. Chemical (gas).
4. Free-falling missiles.
5. Practice.

High-Explosive Bombs

High-explosive bombs are used for the destructive effect caused by blast, fragments, and vacuum pressures created by above-surface explosions, and the mining effect, or earth shock resulting from their detonation.

High-explosive bombs are divided into three main groups as follows:

1. General purpose.
2. Depth.
3. Fragmentation clusters and cluster bomb units (CBU).

General purpose bombs have slender bodies with long, pointed noses. These bombs were primarily designed for external carriage and electric fuzing. However, they still retain the mechanical fuzing capability. An electric fuze may be installed either in the nose or tail fuze cavity. When a proximity function is required, a sensing element is installed in the nose cavity which provides an electrical signal to initiate the tail fuze. GP bombs are equipped with a steel nose plug which is removed when installing a nose fuze or a sensing element. When only a tail fuze is installed, the nose plug is left in place. A base fuze hole shipping plug in the rear of the bomb is removed when an electric fuze is installed in that position.

The loading factor (ratio of explosive weight to total bomb weight) of the general purpose bomb varies from 40 to 60 percent. The explosive filler is either Tritonal or H-6, and is identified by yellow stenciling and a yellow band around the bomb's body. The bomb's body is olive drab. A typical general purpose bomb is illustrated in figure 10-18. Table 10-1 lists the various types and particulars of the current general purpose bombs.

General-purpose bombs may be fitted with a special type of fin assembly (fig. 10-19) which is designed to provide the attacking aircraft with a low-level, high-speed bombing capability without the normal associated hazards of ricocheting bombs or blast fragments.

The Snakeye fin assembly in figure 10-19 presents a low drag configuration in the closed position. In this position, the bomb performs in the normal free-falling manner. In the open position, however, four paddle-like fins are released and deployed into the airstream, thus slowing and stabilizing the bomb during descent.

The aircraft depth bomb, designed for attacking submarines or underwater targets, was widely used during World War II. In the past they have ranged in size from 325 pounds to 700 pounds; the only one used at present is the AN-Mk 54 Mod 1 (fig. 10-20), weighing approximately 350 pounds and loaded with HBX-1.

Depth bombs have a loading factor of about 70 percent and are armed either for impact or for underwater explosion at a preset depth. The setting range is from 25 to 125 feet.

The desired effect of a depth bomb is to create a pressure wave against underwater targets great enough to crush the hull plates of the target.

Depth bombs are painted olive drab with yellow nose and tail bands.

Cluster bomb units and fragmentation clusters are some of the Navy's more recent developments. These units and clusters contain various numbers of small explosive bomblets that are dispersed over a wide area by ram-air action or by the opening of a container by mechanical time fuze action. These bomblets are highly effective against troops, convoys, and other lightly armored targets. Due to their security classification, only limited information is available.

Fire Bombs

Fire bombs (fig. 10-21) are thinskinned containers of gasoline gel designed for use against dug-in troops, supply installations, wooden structures, and land convoys. Fire bombs rupture upon impact and the burning mixture spreads and covers the surrounding area. The chief use of the fire bomb is for low-level, high-speed attacks.

Chemical (Gas) Bombs

Chemical (gas) bombs resemble GP bombs in shape and size. The body of the chemical bomb serves as the filling's container and support for the components. These bombs have a full-length burster charge which splits the bomb case and disperses the FILLING over the area to be contaminated. Chemical bombs are fuzed to explode instantaneously upon contact, or to provide an aerial burst.

110.103
Figure 10-19. — Snakeye.

Table 10-1. — General Purpose Bombs

	Mk 81	Mk 82	Mk 83	Mk 84	M117A1
Weight class (pounds)	250	500	1,000	2,000	750
Assembled weight (pounds)	260	531	985	1,970	750*; 799**
Filler weight (pounds)	100	192	445	945	360*; 384**
Assembled length (inches)	74.1	66.9	118.4	151.5	84
Diameter (inches)	9.0	10.75	14	18	16.1
Suspension (inches)	14	14	14	30	14

*H-6
**Tritonal

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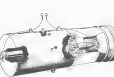
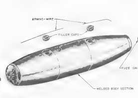


110.152
Figure 10-20.—Aircraft depth bomb.



110.153
Figure 10-21.—Typical fire bomb.

Chemical bombs are painted gray, and have green or red colored bands to distinguish them from other types of bombs. Also, the weight, type filling, model, and lot number are stenciled or stamped on the bomb body.

Free-Falling Missiles

Free-falling missiles are inert bomblets launched from a cluster container. When released from the aircraft, the container is opened by mechanical time fuze action, and the bomblets are spread over a large area. The container holds approximately 10,000 Lazy Dog missiles which are extremely effective against troops and other lightly armored targets.

The cluster case is olive drab with black identifying stencils.

Practice Bombs

Practice bombs, as the name indicates, are used to simulate the ballistic properties of service type bombs for target practice. The general types are subcaliber practice bombs, with cast-metal or steel bodies; full-scale practice bombs, made of sheet metal and filled with water or wet sand; and nuclear weapons practice bombs.

Practice bombs are used for the training of bombing crews in marksmanship. These bombs may use signals which produce a puff of smoke, making it possible to spot the impact location of the bomb. The use of practice bombs instead of live bombs makes it possible to train crews more economically and safely than would be the case with service type bombs.

BOMB FUZES

A bomb fuze is analogous to a gun projectile fuze. It is a device used to cause the bomb to explode at the time and under the circumstances desired, and to prevent the bomb's explosion at other times. This is accomplished by the use of sensitive explosive elements and the required mechanical or electrical devices.

To achieve different types of control for different types and sizes of bombs, many varieties of fuzes are required.

Normally, fuzes are in a safe or unarmed condition to ensure that they do not detonate prematurely. In an unarmed condition, a fuze cannot cause the bomb to explode. A fuze is ready to detonate the bomb when all parts are set so that the fuze can operate. This is the armed condition, which is usually obtained by the ejection of an arming pin, the rotation of an arming vane, the closing of a circuit, etc.

In order for the reader to better understand the basic operating principles of fuzes, it is necessary to discuss some of the more common terminology associated with fuzes. These terms include the following:

1. Arming time—the amount of time or vane revolutions needed for the firing train to be aligned after the bomb is released, or from time of release until the bomb is fully armed.

2. Functioning time—the time required for the fuze to detonate after impact or after a preset time. Functioning time can be (a) instantaneous (functioning time 0.0003 second or less), (b) nondelay (functioning time 0.0003 to 0.0005 second), or (c) delay (functioning time 0.0005 second or longer, up to a maximum time for current fuzes of 33 hours).

3. Safe air travel (SAT)—the distance along the trajectory that a bomb travels in the unarmed condition.

4. Proximity (VT)—the action that causes the fuze to detonate before impact when any substantial object is detected by the fuze at a predetermined distance from the fuze.

5. Carrier or detonator safe—a safety feature incorporated in fuzes to insure that arming will not occur in relatively short distance; i.e., the length of a carrier flight deck.

In general, fuzes may be divided into two main classes—mechanical and electrical. These are arbitrary classes only and refer to the primary operating principles. Each of these classes may be further divided into the methods by which functioning is initiated. For example, mechanical fuzes may be initiated by impact, mechanical timers, and hydrostatic pressure; while electric fuzes are limited to impact and proximity action.

Mechanical Fuzes

In terms of modern ordnance, mechanical fuzes are the oldest and most widely used. A mechanical fuze in its simplest form is like a hammer and primer used to fire a rifle or pistol. A mechanical force (impact, spring tension, or water pressure) drives a striker into a sensitive detonator. The detonator in turn ignites a train of succeedingly insensitive explosives, and eventually fires the main or filler charge.

IMPACT FUZES. — As previously mentioned, impact fuzes are caused to function by the bomb impacting with the target. The functioning may be instantaneous or delayed, whereby the bomb will not explode until a definite period of time has elapsed. These delays are often desirable in making the bomb more effective. This is important if penetration of the target is desired before detonation. This delaying action is incorporated into mechanical impact fuzes by placing a delay element into the firing train. The delay element is usually a tightly packed mixture of black powder and clay. The amount of delay is determined by the ratio of the mixture.

MECHANICAL TIME FUZES. — Mechanical time fuzes contain clock mechanisms to control the desired functioning. Currently, there are two types in use — one designed primarily for airburst and the other for long delayed action after impact. The type designed for airburst commences the delay after a definite amount of air travel or arming vane revolutions. This delay time is adjustable from 4 to 92 seconds. The long delay action fuze requires impact to start the clock mechanism and is adjustable from 30 minutes to 33 hours.

HYDROSTATIC FUZES. — Hydrostatic fuzes are water pressure activated fuzes used in depth bombs or general purpose bombs against submerged targets. Water, entering ports in the fuze body, acts against a bellows system which releases a spring-loaded firing mechanism. The fuze may be set to function from 25 feet to 125 feet below the surface.

Electrical Fuzes

Electrical fuzes have many of the characteristics of mechanical fuzes, but differ mainly in that an electrical impulse is used to initiate the fuze instead of the mechanical action of arming vane rotation. As the bomb is released, an electrical pulse from the delivery aircraft charges a series of capacitors in the fuze. Polarity, frequency, and magnitude of these pulses determines the various arming and functioning times. When electrical fuzes are used in conjunction with proximity sensing devices, the firing pulse is furnished by the circuitry in the sensing device.

Special Safety Features

To provide safe, effective operation, any fuze — whether mechanical or electrical — should provide the following safety features:

1. It must remain safe during stowage and while handling in the normal loading and off-loading procedures.
2. It must remain safe while being carried aboard the aircraft.
3. It must remain safe until the bomb is released and is well clear of the delivery aircraft.
4. Depending upon the type of target, the fuze may be required to delay the detonation of the bomb after impact for a preset time (functioning delay).
5. It should not detonate the bomb if it is accidentally released or if the bomb is jettisoned in the safe condition.

To provide these qualities, a number of design features are used, most of which are common to all types of fuzes. The most important features are detonator safe, shear safe, and delay arming.

Fuzes that are detonator safe do not have the elements of their firing train in proper position for firing until the fuze becomes fully armed. The elements remain firmly fixed and out of alignment in the fuze body while the fuze is unarmed. This increases safety during shipping, stowing, and handling of the fuze. The arming action of the fuze aligns the firing train.

A shear safe fuze will not become armed if its arming mechanism is damaged or completely severed from the fuze body. The arming mechanism of a fuze protrudes the farthest from the bomb, and might be severed from the fuze body if the bomb were accidentally dropped. Shear safe fuzes afford additional security for carrier operations and for externally mounted bombs.

Delay arming mechanically slows the arming of the fuze. It keeps a fuze in the safe condition until the bomb has fallen a sufficient distance away from the aircraft, thus minimizing the effects of a premature explosion. Delay arming helps to make carrier operations safe because a bomb accidentally released during landing or takeoff ordinarily will not have sufficient air travel to fully arm the fuze.

Fuze Arming

When a bomb fuze is unarmed (safe), it cannot function. In some fuzes, a pin through the striker

equivalent to a firing pin) keeps it safe; in others, a "safety block" of metal under the striker head, or a screw securing it to the fuze body, performs this function. In "detonator-safe" fuzes, the detonator or primer is out of line with the firing pin when the fuze is unarmed. Some fuzes use a combination of methods.

Mechanical fuzes are usually armed by the rotation of miniature air screws called arming vanes. These are turned by the passage of air as the bomb falls. The function of the arming wire, when used with vane-armed fuzes, is to prevent the vanes from rotating in the plane's slipstream and arming the bombs before release.

Physically, the arming wire is a length of brass or bronze wire with a flat eyelet at one end. Usually two arming wires are used, one for the nose fuze and one for the tail. One end of the wire is threaded through matching holes in the fuze body and the arming vane. Safety clips (also called Fahnstock clips), slid over the wire next to the fuze, keep the wire from slipping out from between the vanes. The eyelet end of the arming wire is engaged by a retainer on the bomb rack or shackle from which the bomb is suspended. The retainer's functioning is controlled by the pilot's selector switch. If the switch is not on "Safe" when the bomb is dropped, the retainer releases the arming wire with the bomb, so that the vanes cannot rotate and the fuze remains unarmed. If the switch is set on "Arm," the retainer holds the arming wire firmly; the bomb drops without the wire, the vanes turn freely, and by the time the bomb is safely distant from the aircraft, the fuze is fully armed.

Some bomb racks and shackles have several arming wire hooks on them. Thus it is possible to arm one fuze and not the other. This is called selective arming.

Arming of electrical fuzes is accomplished by electrical impulses from the delivering aircraft as mentioned previously.

SAFETY PRECAUTIONS

The hazards of bomb type ammunition are those of the explosives involved, but are considered greater than those of explosive material in bulk form. Bomb type ammunition, when involved in fire, tends to set off a high order mass detonation of all explosive material in close proximity. Evidence accumulated from accidents and from results of special experiments shows that it is possible to explode bomb-type ammunition, particularly those with thin cases, by impact. Bomb type ammunition should not be dropped, dragged, tumbled, or otherwise subjected to shock. Care should be used in loading and unloading operations to prevent damage to the bomb case, projecting lugs, fuze cavities and threads, etc. Only nonferrous type tools should be used for cleaning fuze cavities or threads, or for scraping off drops or crusts of TNT or exudate.

Fire bombs contain great potential hazards. Personnel handling or coming into close contact with this type of ammunition must exercise caution and obey all safety rules. Vapors from the fire bomb mix are generally toxic and highly flammable; therefore, all safety precautions for handling gasoline must be observed. Fire bombs containing white phosphorus (WP) ignitors are extremely dangerous due to the fact that WP ignites upon exposure to air. Fire bombs containing sodium (NA) ignitors, ignite upon contact with water and produce caustic and irritating fumes.

Safety precautions for chemical and chemical bombs vary with the type of chemicals involved and are too numerous to cover in this chapter. Explicit instruction concerning the safe handling, hazards, and other pertinent data may be found in NavOrd OP 2217, Miscellaneous Chemical Munitions (current revision).

Safety involving practice ordnance tends to be overlooked. Of all the accidents and incidents involving ordnance mishaps, the majority can be directly attributed to the mishandling of practice ordnance. Complacency and the amount of items handled often lead to carelessness and accidents. Practice bombs with signals installed must be handled with the same considerations as for live high-explosive bombs. Jarring or dropping the bomb may detonate the signal and result in severe burns or other injuries.

Before handling any type of ordnance, the hazards involved and the necessary safety measures required to safely accomplish the task must be thoroughly understood.

AIRCRAFT GUNS

It was not until late in World War I that anyone visualized the fighting power of an aircraft equipped with automatic guns. During the first part of this period, aircraft were used only for observation purposes and were unarmed. The only protection the pilot or observer had was his sidearm. Rifles were later carried and

fired by the observer, who stood erect in the cockpit.

The first mounted automatic weapons used in combat were adaptations of automatic ground weapons speeded up in rate of fire and fitted with recoil mechanisms to assist in absorbing shock.

The Lewis machinegun caliber .30 was the first automatic weapon to be used in combat aircraft. Later, the Browning machinegun caliber .30 made its appearance, followed by the caliber .50 Browning.

In the meantime, the French Hispano-Suiza 20-mm automatic gun made its appearance. Our Armed Forces began intensive development of a 20-mm aircraft gun about 1937; and a short time later purchased the Hispano-Suiza design from the French. The 20-mm gun was selected as the ideal size aircraft weapon because it was light and compact enough to be mounted in fighter type aircraft, yet it was large enough to fire a high explosive projectile.

Our first model was designated the M1; but before it was ever used, several changes were made, and it became the M2. The M2 was first installed in naval aircraft in 1943 and saw extensive service during the remainder of World War II. However, by this time it had already been decided that a faster firing gun was necessary to compensate for the speedier aircraft that the enemy was producing. This led to the development of the M3, a weapon which came into wide use in 1945. In 1948 when jet aircraft came into use, the Armed Forces realized that a weapon with a higher muzzle velocity and faster rate of fire was necessary. A more effective means of timing gunfire was also desired.

It is an interesting fact that the United States did not introduce, except in experimental quantities, any new type of aircraft machinegun during World War II. The reason for this was the long and tedious program required to develop, refine, and produce a new and reliable service weapon. Our mainstays were the .30 and .50 caliber Browning, and the 20-mm AN-M2 (Hispano-Suiza) aircraft machinegun. Development proceeded on superior automatic aircraft weapons, but the conflict did not last long enough for any to see combat use. Refinement and improvement of the existing machineguns did bring material results. Even today no machinegun in the world can compete with the .50 caliber Browning for reliability.

In the last few years, aircraft weapons have been developed that can very effectively handle certain types of targets that were formerly attacked with guns. Nevertheless, under certain tactical conditions and against certain targets, the gun is still the optimum weapon. Performance requirements are so demanding, however that only an outstanding aircraft gun can fulfill the requirements of today's aerial warfare. Today the firepower per gun and the firepower per pound of gun must be much greater. The most obvious reason for this is that aircraft speeds have more than doubled in the last few years.

The adaptation of pods for the carrying of guns is in line with the present day trend of multiple external stores capability of aircraft. This trend exists in most high performance aircraft where a variety of stores appear as pods. The gun pod adds to the versatility of an aircraft by permitting interchangeability of its armament, such as guns, bombs, rockets, and guided missiles. By the use of gun pods, another variable choice of weapons is available to complete the tactical mission assigned.

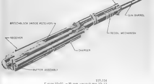
Advances in aerial weapons such as high-speed rockets and guided missiles have limited the use of aircraft guns in current aircraft considerably. Therefore, the coverage of aircraft guns in this text is limited to two guns, the 20-mm aircraft gun Mk 12 and the 20-mm aircraft gun Mk 11 Mod 5, which is a part of the gun pod Mk 4 Mod 0.

20-MM AIRCRAFT GUN MK 12

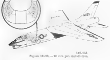
The 20-mm aircraft gun Mk 12 (fig. 10-22) is similar in operating principles to the 20-mm automatic gun M3 used during World War II. The Mk 12, however, fires electric-primed ammunition containing a lighter projectile and a larger powder charge, at a higher rate of fire and an increased muzzle velocity. This weapon is intended for both air-to-ground and air-to-air combat. Figure 10-23 shows the gun installation in the F-8 aircraft.

The Mk 12 gun is an air cooled weapon and operates on both the gas and blowback principles. The gun is electrically fired and continues to operate as long as the firing circuit is closed and ammunition is available. The weapon includes an integral pneumatic charger which is used to operate the breechblock for first round loading, to clear the weapon in case of misfire, and to safety the gun on completion of firing.

The Mk 12 is normally considered to be composed of two major units, the barrel and the



110.154
Figure 10-22. — 20 mm aircraft gun Mk 12.



110.155
Figure 10-23. — 20 mm gun installation.

gun mechanism. However, for purpose of this discussion the weapon is divided into seven major components:

1. Gun barrel.
2. Receiver assembly.
3. Recoil mechanism assembly.
4. Gas mechanism assembly.
5. Breechblock assembly.
6. Buffer assembly.
7. Charger assembly.

These assemblies include all the elements necessary for chambering a round, closing and opening the breech, extracting an empty case, and controlling the recoil and counterrecoil actions. In addition, the gun requires two accessories to make it a complete combat weapon. They are a synchronizing switch, to complete the firing circuit of the weapon, and a pneumatic or spring-driven feed mechanism that feeds the ammunition into the weapon.

Gun Barrel

The barrel is attached to the receiver of the gun by the threads on the breech end of the barrel, and is secured to the receiver by a locking pin which prevents rotation of the barrel after installation. The walls of the chamber are smooth to insure proper gas sealing and extraction. Rifling grooves in the bore extend from just forward of the chamber to the muzzle, interrupted only by the gas port drilled through the top of the barrel.

The exterior of the barrel is tapered in steps from the breech to the muzzle end. An external thread is machined near the center of the gun for attaching the gas bracket and retaining the recoil mechanism. To the rear of this thread is the gas port. An external thread at the muzzle end of the barrel is provided to attach a flash hider, blast suppressor, or barrel support.

Receiver Assembly

The receiver, which is the principal structural element of the gun, houses or supports all of the gun mechanism and provides attaching surfaces for its feed mechanism and gun charger. The charger is on the right side of the receiver and actuates the breechblock for first cartridge loading and safetying action. The gas mechanism (attached to the gun) actuates the breechblock slides to unlock the bolt after firing. The buffer is mounted on the rear of the receiver, and its function is to return the breechblock toward the locked position.

Recoil Mechanism Assembly

The recoil mechanism is a spring mechanism that checks the movement of the recoiling parts of the gun and returns them to battery.

Gas Mechanism Assembly

The gas mechanism unlocks the breechblock and starts it to the rear immediately after a round has been fired. The gas bracket nut secures the gas bracket assembly to the shoulder of the gun barrel. A key fitting into slots in the bottom of the bracket and the gun barrel secures the bracket in its proper angular position on the barrel. The bracket nut is also locked by the same key. The cylinder extension of the bracket guides and supports the piston end of the gas cylinder sleeve assembly. The piston and piston ring form a gas seal between the sliding sleeves and the chamber of the gas bracket. The action insures full effect of the gas pressure admitted through the vent plug. The rear of the sleeve assembly is directed by the guide attached to the top forward end of the receiver. This guide also acts as a stop for the gas cylinder sleeve spring. As the sleeve is forced to the rear by the gas pressure, it contacts a push rod on either side of the receiver. The push rods are aligned with the breechblock slides and unlock the breechblock as they are forced to the rear by the gas cylinder sleeve.

Breechblock Assembly

The breechblock is the reciprocating assembly that loads a round into the barrel chamber, closes the breech, fires the round, and removes the empty case.

Buffer Assembly

The buffer assembly is pneumatically operated. Its function is to absorb the force of the rearward movement of the breechblock, stop this motion, and returns the breechblock to battery. It consists of housing, sleeve, piston, air inlet fitting, check valve, and bleeder valve. Compressed air is admitted to the rear of the piston by the air inlet fitting and the check valve. As the breechblock moves aft and contacts the buffer piston, the check valve closes and traps this air behind the piston. The trapped air is compressed. This retards the rearward motion of the breechblock; and as the breechblock movement is stopped, the trapped air expands and drives the breechblock forward.

Charger Assembly

The charger is a pneumatic mechanism which provides power operation of the breechblock for loading the first round or safetying the gun. The charger piston is actuated by 1,000 psi compressed air from the aircraft. The components of the charger are the charger tube, piston, ram head, and dumping valve. The entire assembly is housed in the charger tube on the side of the receiver. The forward end of the charger tube fits into the charger housing. Six holes are drilled near the rear of the piston tube through an air hose connected to the charger housing. O-rings seal both ends of the charger tube to prevent escape of the compressed air. The dumping valve assembly is screwed into the forward end of the tube.

Synchronizing Switch Mk 1 Mod 1

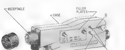
The synchronizing switch shown in figure 10-24 contains three contacts which operate with the breechblock to complete the firing circuit. The case is composed of two halves bolted together. The electrical components consist of the A, B, and C squibs (two forward and one aft as shown), two connectors, and interconnecting wires. The filler plates may be used when mounting the switch to the gun, depending upon whether the receiver of the gun has a recessed or a flat surface. The two forward squibs represent a gap or break in the circuit which must be closed before the gun can fire. The rear squib is the contact for the firing pin which makes contact when the breechblock is in battery. In operation the break between the two forward squibs is closed by the breechblock before it reaches battery position.

Feed Mechanism Mk 7 Mod 2

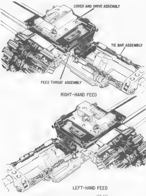
The 20-mm feed mechanism Mk 7 Mod 2 is powered by an air motor which is supplied with compressed air from the aircraft's air system. It is mounted on top of the gun receiver body and secured by six locking lugs and two tie bar assemblies. (fig. 10-25). The design features include a low profile, light weight, and the ability to sustain a high rate of gunfire. The mechanism can be quickly installed and removed. Identical components are used for right- and left-hand installation.

Ammunition Belting System Mk 2 Mod 0

Ammunition belting system Mk 2 Mod 0 is a motor-driven assembly for mechanically linking 20-mm aircraft ammunition in preselected ratios to form a continuous belt.



110.156
Figure 10-24.—Synchronizing switch Mk 1.



110.157
Figure 10-25.—20 mm feed mechanism Mk 7.

110.158
Figure 10-26. — Gun pod Mk 4 Mod 0.

110.159
Figure 10-27. — 20 mm aircraft gun Mk 11.

This system automatically performs three functions:

1. It feeds the links and connects them together in a continuous string.
2. It selects and feeds different types of ammunition in preset ratios.
3. It either links or delinks at speeds up to 250 pounds per minute. Normally motor driven, the system may also be manually operated.

GUN POD MK 4

The Mk 4 gun pod with the Mk 11 gun is a 20-mm gun system capable of firing 4,000 rounds per minute. Loaded with 750 rounds the pod weighs 1,385 pounds. It is electrically controlled from the aircraft and is self-powered. Charging, clearing, and ammunition boost functions are powered by a 3,000 psi pneumatic supply inside the pod. Alternate lower rate of fire and automatic charge are optional features.

The advantage of mounting guns in pods instead of within the aircraft fuselage or wings are numerous, including such factors as (1) reduced gunfire blast and vibration, (2) positive clearance of expended cases and links from aircraft, (3) improved accuracy due to a single mount harmonization, (4) quick turnaround, and (5) safety from gun hazards such as gun gas, double feed, hangfire, and cookoff.

The pod can be flown and fired at speeds up to Mach 1.2 at 10,000 feet and Mach 2.2 at 40,000 feet.

The gun system consists of the gun pod (fig. 10-26), the Mk 6 Mod 4 link, and Mk 100 series ammunition. The 20-mm aircraft gun Mk 11 Mod 5 (fig. 10-27) is part of the gun pod, and in turn is made up of two items: the 20-mm gun mechanism Mk 11 Mod 5 and the 20-mm gun loader Mk 2 Mod 1. The Mk 11 gun is located on the centerline of the pod, with the barrels in a plane through the mounting lugs.

The Mk 11 gun is a self-powered, twin-barrel revolver weapon employing the Marquardt gun cycle. It fires at 4,000 ± 200 rounds per minute and is fed by two ammunition belts. The Mk 11 Mod 5 gun described here is the production configuration. It weighs 225 pounds ready to fire, is 78.5 inches long, and has a life exceeding 100,000 rounds. The Mk 11 gun fires the standard Mk 100 series ammunition (as used in the 20-mm Mk 12 gun).

CHAPTER 11

COASTAL AND RIVERINE CRAFT ARMAMENT

Throughout our history coastal and riverine craft have played a very important part in achieving victories, on sea and shore. This has been true from the American Revolution to the Vietnam conflict.

Coastal and riverine craft, many of which were converted from World War II landing craft, have been used extensively in the Vietnam conflict. Their armament, which varies from craft to craft, ranges from .30 caliber machine guns to 105 mm howitzers. This chapter will acquaint you with some of these and their armament, including its operation. Keep in mind that most of these craft are of a temporary nature—activated and built only for use in the Vietnam conflict—and may or may not be in service once the Vietnam conflict is over. However, future involvement in a similar type of warfare may again require their use.

COASTAL CRAFT AND THEIR ARMAMENT

Coastal craft include patrol gunboats (PGs), hydrofoil gunboats (PGHs), fast patrol boats (PTFs), and fast patrol craft (PCFs). (Some coastal craft, such as the PTF and the PCF, also may be used for riverine service.) A representative number of these craft and their armament will be briefly discussed in this section. Again, keep in mind that the armament on one boat may be different from that on another boat of the same type.

PATROL GUNBOAT ARMAMENT

A patrol gunboat's armament consists of a single 3"/50 gun mount forward, a single 40 mm gun aft, and four .50 caliber machine guns in twin mounts atop the pilot house. Ashville Class PGs, except USS Antelope (PG-86) and USS Ready (PG-87), have Mk 63 gun fire control systems (fig. 11-1). Antelope (fig. 11-2) and Ready have Mk 87 weapons control systems. The PG's weapons are capable of inflicting heavy damage upon light shipping and enemy personnel ashore.

3"/50 Gun Mount

The 3"/50 used on patrol gunboats (fig. 11-2) is a rapid-fire, semiautomatic, enclosed single gun mount. Although the 3"/50 gun was designed primarily for air defense, it can be used very effectively against surface and shore targets.

The 3"/50 gun on a PG is enclosed in a fiber glass shield; 3"/50 guns on other ships may be open mounts or enclosed in either fiber glass or aluminum shields. The description and operation of the 3"/50 gun are covered in chapter 5.

40 MM Mount Mk 3

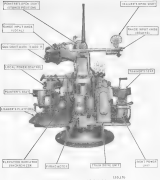
The single 40 mm mount (fig. 11-3) on the PG is a power driven, electrically controlled, dual-purpose open mount. It is controlled by synchro signals, which drive the mount in train and elevation. The controlling signals may be furnished either by a Local Power Control unit mounted on the carriage (fig. 11-3) or by a fire control director. A Local-Automatic selector switch on the carriage determines which set of synchro signals provides the control.

When the Local-Automatic switch is positioned for local control of the power drives, the gun pointer controls both the train and the elevation power drives by manipulating the handgrips of the Local Power Control unit. The pointer tracks the target with a gunsight that is mounted on the gun mechanism and moves with the gun. He may fire the gun electrically by depressing a foot-operated firing switch or manually by depressing the foot-firing pedal.

When the mount is in automatic control, it will follow the train and elevation gun order signals from the director or computer. Electric power firing of the gun can be initiated by the director operator and controlled by the gun

3.269-85
Figure 11-1.—USS Gallup (PG 85), an Ashville Class aluminum-hulled gunboat. She is armed with a 3-inch gun forward and a 40 mm gun aft, and her speed exceeds 33 knots.

3.269-86
Figure 11-2.—USS Antelope (PG 86), with its FCS Mk 87 radome clearly visible above the pilot house.



110.170
Figure 11-3. — 40 mm mount Mk 3 Mod 4, rear view.

crew. Manual gun operation by handcranks is possible whenever power operation is not feasible.

Various safety features such as power-to-manual interlocks, securing pins, firing cut-out cams, power-operated limits, train and elevation positive stops, and buffers are provided. These safety features, along with other features of the mount, are explained in detail in OP 1289.

Some of the components of the 40 mm mount, such as the trainer's and the pointer's open sights, local and remote range input knobs, Local Power Control unit, and the gun sight are shown in figure 11-3.

.50 Caliber Machine Gun (M2HB)

The .50 caliber machine gun on the patrol gunboat is a Browning recoil-operated, belt-fed, air-cooled gun. Although it is primarily an antiaircraft weapon used by the Army, the Navy has adopted it for use aboard ship, against both surface and air targets.

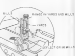
The mechanism of the weapon and its principles of operation are described in detail in Army Field Manual FM 23-65.

Main characteristics of the .50 caliber machine gun are as follows:

Weight of gun with barrel.	84 pounds
Overall length.	65 1/8 inches
Length of barrel	45 inches
Lands and grooves	8 each
Rate of fire (rounds/minute)	500
Maximum range.	7,400 yards
Effective range	2,280 yards
Cooling	Air
Barrel twist.	Right hand; one turn in 15 inches
Direction of feed	Optional (left or right)
Mode of fire.	Full automatic or semiautomatic
Type of feed.	Disintegrating metallic link belt
Muzzle velocity	2900 feet/second

An exterior view of the machine gun is shown in figure 11-4, and a closeup of the rear sight is shown in figure 11-5. The sight is a leaf and blade type. It is graduated in both yards and mils for range—from 100 to 2600 yards and 0 to 82 mils. A windage screw allows for a wind correction of 5 mils either to the right or the left.

84.112
Figure 11-4.—Browning .50 caliber M2 machine gun (shown on the ground mount M3).



110.171
Figure 11-5.—Sight leaf, metallic sight.

The gun normally uses a left-hand feed, but by changing the position of certain parts, it can be fed from the right side.

FAST PATROL BOAT (PTF) ARMAMENT

Fast patrol boats with hull numbers 17-26 (fig. 11-6) have the following installed ordnance: one 81 mm mortar, a single 40 mm mount, 2—20 mm single mounts, and 1—50 caliber machine gun mounted over the mortar. The 81 mm mortar with its piggyback .50 caliber machine gun (fig. 11-7) is located in the bow section of the boat. One of the 20 mm guns is mounted on the

110.172
Figure 11-6.—Fast patrol boat, 17-26 class.

29.320;84.112
Figure 11-7.—81 mm mortar and piggyback .50 caliber machine gun.

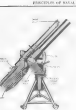
starboard side and the other is mounted on the port side.

PTFs with hull numbers 3-16 have 2—40 mm guns—one forward and one aft—and 2—20 mm guns—one to starboard and the other to port. (The .50 caliber machine gun is the same weapon as the one described earlier. Therefore, it will not be discussed further.)

81 MM Mortar

The 81 mm mortar shown in figure 11-7 is a Mk 2 Mod 1 design; the one in figure 11-8 is a Mk 2 Mod 0. The major design difference between the two is that the Mod 1 has the piggyback machine gun.

The mortar is capable of firing high explosive shells, illuminating shells, and white phosphorous (WP) smoke shells. This capability makes it an effective weapon in bombardment, laying smoke screens, and providing nighttime target illumination. Fuzes for the mortar's ammunition are of two types: point detonating and time. However, there are three types of fuze actions because point detonating fuzes can be either superquick (explode on impact) or delay (activate



29.320.1
Figure 11-8.—81-mm mortar Mk 2 Mod 0 (right side view).

on impact but explode a fraction of a second later).

The mortar is simple in design. It can be operated by one man, though two usually perform this duty. It is designed for free swinging in both train and elevation for quick change in direction, or it can be fired from a fixed position, by either drop-fire or controlled trigger fire. (In drop-fire, the projectile is fired as soon as it slides down the barrel and hits the firing pin; trigger fire is similar to firing a handgun.)

The 81 mm mortar has an open yoke-type sight mounted at the left side of the slide (fig. 11-9). It is a manually-adjusted arrangement with offset limits of 14°20' deflection, right and left, and 75° sight angle. The mortar has an elevation scale that is graduated in 5° increments from -30° to +75° and a training scale graduated in 1° increments from 0° to 360°.

Additional information on the 81 mm mortar, which is also mounted on Hydrofoil Gunboats (PGHs) and Fast Patrol Craft (PCFs), can be found in OP 1743.

29.320.2
Figure 11-9.—81 mm mortar sight Mk 1.

20 MM Gun

The 20 mm gun on the PTF (and other small craft) was originally designed in the early 1930's for use on aircraft. The first known successful application of this weapon for use on surface vessels was on the Navy's small boats in

Vietnam—boats such as PCFs, PBRs and ASPBs. The 20 mm gun may be mounted in an open mount arrangement, as on the PTF, or in an enclosed mount (fig. 11-10).

For discussion purposes, the 20 mm aircraft gun may be considered to be divided into seven major components (fig. 10-27) as follows:

1. Gun barrel
2. Receiver assembly
3. Recoil mechanism assembly
4. Gun mechanism assembly
5. Breechblock assembly
6. Buffer assembly
7. Charger assembly

These assemblies include all the elements necessary for chambering a round of ammunition, closing and opening the breech, extracting an empty case, and controlling the recoil and counterrecoil actions. Additionally, the gun requires two accessories to make it a complete combat weapon—a synchronizing switch to complete the firing circuit and an ammunition feed mechanism.

In addition to being useful against aircraft, the 20 mm gun can be used against small craft and personnel. Its primary uses on the Navy's small boats in Vietnam are against personnel and small craft. A detailed description of the 20 mm aircraft gun can be found in Aviation Ordnanceman 3 & 2, NavPers 10345 series or OP 3476.

110.173

Figure 11-10.—Mk 48 gun mount with 20 mm gun and Mk 19 machine gun.

FAST PATROL CRAFT (PCF) ARMAMENT

The fast patrol craft, "swift" type (fig. 11-11), is generally equipped with an 81 mm mortar with a piggyback machine gun mount, aft, and a twin .50 caliber machine gun mount atop the pilot house. Also, they may be equipped with a Mk 19, 40 mm machine gun mounted forward of the pilot house and M60 (7.62) machine guns. PCFs, as well as other small boats, are equipped with hand-carried ordnance such as M79 grenade launchers and handguns, as the need arises.

HYDROFOIL GUNBOAT (PGH) ARMAMENT

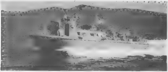
Presently, there are two hydrofoil gunboats in service. Both are armed with 1—40 mm gun forward, 4—.50 caliber (two twin mounts) machine guns atop the pilot house, and 1—81 mm mortar aft. Hydrofoil Gunboat Tucumcari (PGH-2) is shown in figure 11-12. Its high speed capability (above 40 knots), ease in maneuvering, and variety of weapons makes it very useful for coastal operations. (Both PGH-1 and PGH-2 are expected to be used for ordnance experimental purposes in the near future.)

RIVERINE CRAFT AND THEIR ARMAMENT

Riverine craft as we know them today consist of a variety of small boats with a variety of armament, much of which is the same as that for the coastal craft discussed earlier. Some of these boats were built specifically for riverine use; others are converted World War II landing craft, commerical craft, and pleasure craft. They include the river patrol boat (PBR), assault support patrol boat (ASPB), monitor (MON), armored troop carrier (ATC), command and control boat (CCB), patrol air cushion vehicle (PACV), and the river minesweeper (MSR). The armament of a representative number of these craft will be discussed in the following paragraphs.

RIVER PATROL BOAT (PBR) ARMAMENT

The river patrol boat shown in figure 11-13 is armed with 3—.50 caliber machine guns and a 40 mm (M79) grenade launcher. The twin machine gun mount is located in the bow section of the boat. The 40 mm grenade launcher is hand carried. The single machine gun is located near the boat's stern.



134.174
Figure 11-11. — Fast patrol craft, "Swift" type.

3.88(134)
Figure 11-12. — Hydrofoil gunboat _Tucumcari_ (PGH 2) with hydrofoils in the water.

3.272

Figure 11-13. — River patrol boat on a routine patrol.

The armament of different PBRs varies. Some PBRs have a 40 mm machine gun mounted over the single .50 caliber machine gun. Others have 60 mm mortars and 7.62 mm machine guns in addition to their .50 caliber machine guns and 40 mm machine gun.

40 MM Grenade Launcher M79

The M79 grenade launcher is a single-shot, shoulder fire weapon. It is breech loading and chambered for a 40-mm metallic cartridge case with internal primer. It is trigger-fired the same as a shotgun. It even resembles a shotgun somewhat (fig. 11-14). Because of its versatility, the grenade launcher is issued to most of the riverine craft, and its primary use is the launching of antipersonnel projectiles against enemy ground forces. The operation and maintenance of the M79 grenade launcher is described in Army Technical Manual TM 9-1010-205-12.

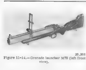
60 MM Mortar

Like the 81 mm mortar, the 60 mm mortar (fig. 11-15) can be used for bombardment, laying smoke screens, and for providing nighttime target illumination. It too has a recoil-counter-recoil mechanism to reduce brake load and a trigger-firing mechanism.

The main characteristics of the 60 mm mortar are as follows:

Weight.	133 pounds
Length.	54 1/4 inches
Width	14 inches
Height	57 3/4 inches
Mode of fire.	drop or trigger
Type of feed.	hand
Rate of fire	10-18 rounds per minute
Maximum range.	1,850 yards
Effective range	1,000 yards
Muzzle velocity	493 feet per second
Barrel twist.	none
Barrel length	25 5/8 inches
Cooling	air

Operationally, the 60 mm mortar is similar to the 81 mm mortar. The major differences between the two are the greater muzzle velocity, larger projectile, and longer range of the 81 mm mortar.



29.366
Figure 11-14.—Grenade launcher M79 (left front view).

7.62 MM Machine Gun M60

Another weapon that is commonly used on the PBR and other riverine craft (as well as on some coastal patrol craft) is the 7.62 mm machine gun. This is the Army's machine gun mounted for use on Navy small boats, and it is capable of engaging distant targets (up to 3200 meters) with a heavy volume of controlled and accurate fire.

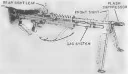
The M60 machine gun (fig. 11-16) is an air-cooled, belt-fed, gas-operated automatic weapon. The ammunition for this weapon, which fires from the open-bolt position, is fed into the gun by a disintegrating metallic split-link belt. Main characteristics of the gun are as follows:

Caliber	7.62 mm NATO (.308 caliber)
Weight	22 pounds
Length	43.5 inches
Width	3 inches
Height	5 inches
Mode of fire	automatic
Direction of feed	left hand
Type of feed	ammunition can
Rate of fire	550 rounds per minute
Maximum range	3,200 meters
Effective range	1,100 meters
Muzzle velocity	2,750 feet per second
Barrel twist	right hand, one turn in 10 inches
Barrel length	24 inches
Cooling	air

29.320
Figure 11-15.—60 mm mortar.

The M60 has a front sight permanently affixed to the barrel. The rear sight leaf is mounted on a spring-type dovetail base. The range plate on the sight leaf is marked for each 100 meters, from 300 meters to the maximum effective range of 1,100 meters. Range changes may be made by using either the slide release or the elevating knob—the slide release for major changes and the elevating knob for minor changes.

A detailed description of the 7.62 machine gun M60 is found in Army Technical Manual FM 23-67.



45.678

Figure 11-16.—7.62 mm machine gun, M60, bipod mounted.

Miscellaneous Ordnance

Some PBRs, as well as other small boats, carry night vision equipment, small arms, pyrotechnics, and demolition grenades. The night vision equipment (sight) is used to see enemy movement at night or during poor visibility conditions. It is hand held or mounted on the M16 rifle. Small arms carried by the PBR consist of a 12 gauge shotgun, 3—M16 (5.56) rifles, 2—40 mm grenade launchers, a .38 caliber revolver, and an ordnance locator. The small arms are especially useful for boarding and search operations. The pyrotechnics are used for signaling, by smoke or illumination.

The miscellaneous ordnance carried by any boat at a given time will vary according to its assigned mission.

ASSAULT SUPPORT PATROL BOAT (ASPB) ARMAMENT

Armament of ASPBs may vary, but generally it consists of 3—Mk 26 gun mounts (with either .50 caliber machine guns or Mk 20, 40 mm machine guns), 2—20 mm machine guns, and 2—Mk 19 high-velocity grenade machine guns—plus small arms and night vision devices.

The ASPB (fig. 11-17), with its assortment of armament, is used mainly for patrolling inland waterways and for supporting troop landings and movements. A description of its armament, except for the .50 caliber machine gun which was described earlier, is in the following paragraphs.

Mk 26 Gun Mount

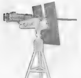
The Mk 26 mount is a universal tripod, lightweight unit developed for the .50 caliber heavy barrel machine gun and adaptable for mounting other weapons. The mount is quite versatile with respect to location on a variety of small boats. It weighs 205 pounds and is 59 inches high. It can elevate through a 100° arc—from -15° to 85°. Figure 11-18 shows the Mk 26 with a .50 caliber machine gun mounted. The Mk 20 machine gun requires an adapter for its installation on the Mk 26 mount.

On other small craft, the Mk 26 may have other ordnance mounted—such as the 7.62 mm machine gun or the Mk 20 machine gun.

Mk 20 Machine Gun

The Mk 20 machine gun (fig. 11-19) is a fully automatic, low-velocity grenade machine gun used as an antipersonnel weapon. It fires the same round as the M79 grenade launcher, and it utilizes a metallic link fed from a 24-round ammunition can. The gun was designed to be

110.174
Figure 11-17.—Assault support patrol boat, on patrol.



64.112
Figure 11-18.—.50 caliber machine gun on Mk 26 gun mount.

110.175
Figure 11-19.—Mk 20 grenade gun (low velocity).

pedestal mounted; however, it is recoilless and lends itself to multiple mounting systems such as tripods or bipods or, if necessary, it may be fired from a hand-held position.

To fire the weapon, the first cartridge is loaded manually into firing position. After that

shot is fired, the remaining operation is automatic or semiautomatic—depending upon the mode of fire.

Following are some characteristics of the Mk 20 machine gun:

Caliber.	40 mm
Weight	26 pounds
Length	27 inches
Width.	9 inches
Height	7 inches
Mode of fire	full automatic or semiautomatic
Direction of feed.	left hand
Type of feed	mechanical, link
Rate of fire	250 rounds/minute
Maximum range	400 meters
Effective range	350 meters
Muzzle velocity	230 feet/second
Barrel twist	right hand, one turn in 48 inches
Barrel length	12 inches
Cooling.	air

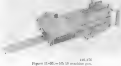
This weapon, with its relatively high rate of fire, can inflict heavy damage upon enemy troops.

Mk 48 Gun Mount

The Mk 48 gun mount is a medium-armored, small-caliber, flexible multiple-gun mount for use on small craft employed in patrol, escort, and support duties. The mount provides fire power effective against other small craft as well as personnel and shore emplacements. It has unobstructed peripheral vision for easy target recognition from all angles.

The Mk 48 mount comes in several mods. Its mod depends upon its ordnance suite. The Mod 0 mount has one Mk 19 machine gun and one 20 mm machine gun; the Mod 1 has one Mk 19 machine gun and two 7.62 mm machine guns; and the Mod 2 has one Mk 19 machine gun and two .50 caliber machine guns.

The ASPB in figure 11-17 has a Mk 48 Mod 2 mount and a Mk 48 Mod 0 mount like the one shown in figure 11-19. The mount is 39 inches above the deck. It is manually operated through 360° in train and can be elevated from −15° to 65° (a total of 80°). It has a periscope-type sight for daytime use and a light amplification type for use at night. The Mod 0 (as stated earlier) has a 20 mm machine gun and a Mk 19 machine gun. The 20 mm gun is identical to those described earlier for the fast patrol boat. The Mk 19 machine gun (fig. 11-20) is a mechanically-fed, blowback-operated weapon designed to fire 40 mm high velocity grenades.



110.176
Figure 11-20.—Mk 19 machine gun.

It can be fired by hand or remotely by using a solenoid, its main characteristics are as follows:

Caliber.	40 mm
Weight	46 pounds
Length	34 inches
Width.	9.5 inches
Height	7.5 inches
Mode of fire	full automatic or semiautomatic
Direction of feed.	left to right
Type of feed	mechanical, link
Rate of fire	375 rounds/minute
Maximum range	2,200 meters
Effective range	1,600 meters
Muzzle velocity	800 feet/second
Barrel twist	right hand, one turn in 48 inches
Barrel length	12 inches
Method of operation	advanced primer ignition
Cooling.	air

Although the Mk 19 40 mm machine gun was initially designed for use on the Mk 26 deck mount or on the Mk 48 shielded mount, further adaptation has enabled it to be used in other applications (e.g., by ground forces and in some helicopters).

Miscellaneous ASPB Armament

The ASPB has an allowance of small arms and night vision devices similar to that of the PBR. Additionally, some have two 4 tube Mk 47 rocket launchers (3.5 bazookas).

MONITOR (MON)
ARMAMENT

The monitor, a converted landing craft (LCM), provides fire support for riverine operations. It has two basic hull configurations — the HOWITZER and the FLAME SYSTEM. The Howitzer configuration (fig. 11-21) has a 105 mm howitzer mount forward, 2 — Mk 48 Mod 0 gun mounts aft (one to port and the other to starboard), and 2 — 7.62 machine guns installed on Mk 26 gun mounts. The flame system configuration has two flame throwers instead of the howitzer and a Mk 20 machine gun in place of one of the 7.62 mm machine guns. Both configurations have small arms and night vision devices.

The heavily armored monitor is popularly referred to as the "battleship" of the riverine fleet, its 105 mm howitzer or flame thrower gives it added "punch" in routing the enemy.

OTHER COASTAL AND RIVERINE CRAFT AND THEIR ARMAMENT

The Navy has several other types of coastal and riverine craft. Some are used for one specific purpose while others have multiple uses. Whether these craft are in an active or a reserve status depends upon the current requirement. Some of these craft and their armament are as follows:

1. Patrol Air Cushion Vehicle (PACV). The PACV (fig. 11-22) travels on a cushion of air about four feet thick. Flexible air-actuated trunks provide obstacle clearance and ditch-crossing capability over land and improved riding qualities over water. The PACV has been highly successful in its operation in the marshy plains of South Vietnam. It is armed with a twin Mk 56 .50 caliber machine gun mount, two 7.62 mm machine guns, and two 40 mm grenade launchers.

2. Armored Troop Carriers (ATCs). These craft were converted from LCM-6 landing craft. Their main purpose is to transport troops, small vehicles, field artillery, and supplies. Heavily armored, they are fitted with steel helicopter platforms to facilitate evacuation of wounded personnel, logistics resupply, and as emergency landing platforms for damaged helicopters. Their armament consist of 1 or 2 — 20 mm machine guns, 2 — .50 caliber machine guns, 1 — 40 mm Mk 19 grenade machine gun, and 2 — Mk 20 machine guns.

3. Command and Control Boat (CCB). The CCB (fig. 11-23) serves as an afloat command post, which provides command and communications facilities for ground force and boat group commanders. They are heavily armored and are armed with 2 — 20 mm machine guns, 2 — .50 caliber (or 7.62 mm) machine guns, and 2 — Mk 19 machine guns.

4. River Minesweepers (MSR). River minesweepers are converted landing craft. They are heavily armored craft that are used for clearing mines from the rivers. MSRs are armed with two Mk 48 Mod 0 mounts amidships — one to starboard and one to port — and a .50 caliber machine gun.

5. Coastal Minesweeper (MSC). The MSC is constructed throughout of wood and other

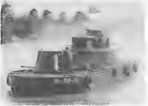


Figure 11-21.—Howitzer configuration monitor. 134.172

110.177
Figure 11-22.—The patrol air cushion vehicle, riding on a 4-foot cushion of air, can patrol or chase over any type of terrain.

110.175
Figure 11-23. — Command and control boat (CCB).

110.178
Figure 11-24. — Bluebird class coastal minesweeper (with twin 20 mm mount forward).

110.180
Figure 11-25. — Albatross class coastal minesweeper (old) has one 40 mm mount forward.

materials with a low magnetic attraction. The Bluebird Class (fig. 11-24) has one twin 20 mm mount forward. The Albatross Class (fig. 11-25) are classified as MSCOs and have a single 40 mm mount forward. (The 20 mm twin mounts shown in the illustration have been removed from active MSCOs.)

These are but a sampling of the various small boats used in coastal and riverine operations. Again, bear in mind that the armament may vary considerably from boat to boat. For example, the armament on one PBR may be quite different from the armament on another PBR.

CHAPTER 12

UNDERWATER ORDNANCE

Underwater ordnance includes weapons used in destroying or disabling an enemy ship by means of an underwater explosion. Weapons employed in underwater warfare include torpedoes, mines, depth charges, depth bombs, hedgehogs, and rockets.

Some of the Navy's most recent developments in rocket-assisted underwater weapons such as Asroc, Subroc, and Astor are discussed briefly in the next chapter. A more detailed discussion of these and other underwater weapons may be found in (the classified publication) Navy Missile Systems, NavPers 10785 series. This chapter is limited to a discussion of torpedoes and mines.

A torpedo is a self-propelled weapon that carries a high-explosive charge to an enemy ship. A mine is a thin-cased weapon filled with high explosives and designed to explode under water when struck or closely approached by a ship. The ancestor of both was David Bushnell's powder keg with contact triggers (caused keg to explode on contact with an object) attached (fig. 12-1), many of which he floated down the Delaware River toward blockading British ships during the American Revolution.

Much emphasis is still being placed on improving mines and torpedoes. One reason is the fact that an underwater explosion can do more damage than an above-water explosion using the same explosive charge. Since water is practically incompressible, it transfers most of the force of an explosive shock directly to the hull of the target ship, whereas air absorbs much of the force of an explosion in the atmosphere.

INTRODUCTION TO TORPEDOES

Credit for the first self-propelled torpedo goes to a Captain Lupius of the Australian Navy. Captain Lupius worked out his idea during the American Civil War, but he didn't have the mechanical know-how to actually build the torpedo.

In 1864 he took his plans to Robert Whitehead, a British engineer. After two years of work, Whitehead produced a short torpedo, 14 inches in diameter, with 18 pounds of dynamite in its warhead. It was powered by a piston engine operating on compressed air at 700 psi. Whitehead's first torpedo ran at 6 knots, for about 100 yards. On some of its tests it ran along the surface; on others it dived to the bottom.

Whitehead invented many of the devices that are found in modern torpedoes. For example, the air system of the Whitehead torpedo was controlled by a stop valve, a charging valve, a starting valve, and a reducing valve. To keep his torpedo running at the proper depth, Whitehead invented a depth mechanism containing a hydrostatic diaphragm and pendulum. (Air-steam torpedoes have all these parts.) To keep his torpedo on course Whitehead invented a servomotor to operate the steering rudders. Whitehead developed the idea of replacing the warhead with an exercise head for practice shots.

While Whitehead was improving his torpedo, other inventors were busy, too. Most of those experimental torpedoes were abandoned shortly after they were tested. Air-steam torpedoes are based on Whitehead's ideas. But three key

56.1
Figure 12-1. — Bushnell's powder keg mine, ancestor of the torpedo and mine.

improvements on Whitehead's basic invention have been made:

(1) substituting turbines for the piston engine,
(2) adding fuel to superheat the compressed air, and
(3) adding a gyroscope to control the steering engine.

As previously stated, a torpedo is a self-propelled weapon. Its principal requirements are, therefore, a charge of explosive and a power plant. As a practical weapon, a torpedo must have a number of other features, including:

1. A shell, or housing, strong enough to support the explosive charge, power plant, and related mechanisms, and strong enough to withstand the shock of launching.
2. A source of energy for the power plant, and for the torpedo control mechanisms.
3. An exploder that will detonate the explosive charge when the torpedo reaches its target, but which will remain inoperable while the torpedo is close to the firing ship.
4. Control mechanisms that hold the torpedo on a preset course, at a preset depth.
5. One or more propellers to drive the torpedo through the water.
6. Tail vanes and rudders, to control course and depth.
7. Homing torpedoes require, in addition, a homing device which will enable the torpedo first to search for the target, then to sense the target as it approaches, and finally to steer itself on a collision course with the target. At present, homing devices function on acoustic principles.

All torpedoes are similar in general exterior appearance. They differ considerably, however, in function and capabilities. Torpedoes may be classified in several ways:

1. By their power plants (air-steam, chemical, electric, or solid fuel).
2. By the vehicle from which they are launched (surface ship, submarine, or aircraft).
3. By speed and range.
4. By the type of exploder used. The impact exploder operates only when the torpedo actually strikes its target. The influence exploder (which will not be detailed in this text) operates when the torpedo passes near its target.
5. By type of control mechanism. The control mechanism in a conventional torpedo holds the torpedo on a previously calculated collision course with the target. A homing torpedo, after enabling (commencing to search), runs on a preset "pattern-running" course until it acquires the target. It then receives steering signals from the homing system and attacks the target. If the target is lost, the torpedo shifts back to a search pattern until it acquires the target once more.

Although torpedoes are constantly being improved as to speed, accuracy, and lethality, the exterior shape has remained almost the same except for a reduction in length. Most torpedoes are elongated cylinders with relatively blunt noses and tapering tails. Standard diameters are 10, 12.75, 19, and 21 inches. Most torpedo tubes consist of 21" diameter barrels and with the proper equipment can accommodate torpedoes of any diameter. The nose may be either ogival, spherical, or flat. The tapering tail mounts fins with vertical rudders and horizontal stabilizers (the latter corresponding to elevators in an aircraft) as well as either one or two screws (propellers). If there are two screws, they rotate in opposite directions (counterrotation), so that the reaction of a single screw will not cause the torpedo body to rotate. If a torpedo has a single screw, either its tail fins are canted or its body is fitted with canted longitudinal ribs or ridges to produce a torque opposing that of the single screw as the torpedo passes through the water.

FUNCTIONAL ELEMENTS

A torpedo is generally constructed in four sections — head, midsection, afterbody, and tail. Each section is concerned with a specific function. Most homing torpedoes, however, have only three sections: the afterbody and tail are usually combined.

The head may be either a warhead or an exercise head. The warhead contains the main charge and its exploding device, as well as (in a homing or influence-fired torpedo) the acoustic and magnetic sensing elements used in steering the torpedo and firing the charge. An exercise head contains either liquid ballast (water) or solid ballast (lead weights) which is released at the end of torpedo run, causing the torpedo to surface.

The midsection (which may have different names in different types of torpedo) in general houses energy-storing or energy-supplying devices, such as compressed air flasks, batteries, fuel and oxidizer tanks, and the like. It may also contain some controlling devices such as valves

or some guidance equipment. The midsection may actually be constructed as two parts. In air-steam powered torpedoes, it is called the air flask section; in some electric-powered torpedoes, it is called the battery compartment.

The afterbody contains the propulsion engines and gearing and guidance equipment.

The tail includes the fins and control surfaces, the exhaust system (if any), and the screws that propel the torpedo. All standard torpedoes now in active service use screw propulsion.

Torpedoes may be fitted with other accessory parts required for special launching methods. Thus, torpedoes modified for rocket or missile propulsion (such as those used with Asroc) may be fitted with parachutes and buffers to reduce shock when they enter the water, and with special hardware for attachment of airframes or suspension from aircraft.

LAUNCHING METHODS

There are four principal ways to launch a torpedo — by firing it from a tube, by dropping it from a rack, by propelling it part of the way to its target as a rocket payload, or by letting it swim out.

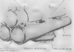
Aircraft drop torpedoes from launching racks; usually, an aircraft carries only a single torpedo. A helicopter can carry one or two torpedoes for ASW work.

The Navy's older destroyers as well as FRAM destroyers, DEGs, and DLGs carry torpedoes in the 3-barrel Mk 32 launcher (fig. 12-2).

The tube is usually carried amidships. It can be trained through a wide arc, so that torpedoes may be fired over either side of the ship. Compressed air expels the torpedoes from the tube with enough force to clear the ship. These 3-barrel tubes have all but superseded an older 5-barrel tubes that used black-powder impulse charges to expel the torpedo.

Some destroyer escorts are fitted with fixed, nontrainable tubes — usually four of them — located above the main deck with their muzzles extending through the sides of the deck house. Others have twin tubes protruding through the ship's stern.

Submarines fire torpedoes from fixed, below-water tubes. On firing, the torpedoes are expelled from the tubes by hydraulic ejection or compressed air or they swim out under their own power. Spare torpedoes are carried in ready racks near the tubes.



3.129(51)
Figure 12-2. — Torpedo tube Mk 32.

The torpedo is an important weapon of all modern destroyers. Torpedoes are the principal armament of many submarines and, under certain conditions, of aircraft. Torpedoes also constitute the payload of more advanced ASW weapons such as Asroc.

The tactical use of torpedoes has changed tremendously over the past few years. Their use in surface engagements is likely to be much less frequent than it was before. The outcome of a battle will most likely be decided before the enemy is within torpedo range.

On the other hand, torpedoes have become very important in ASW. In this application they may be launched from air, surface, or undersea craft to attack a submerged target even when the target's exact position and depth are unknown.

AIR-STEAM TORPEDOES

Although the submarine-launched air-steam torpedo does not represent the most advanced state in the art of torpedo design, it still is used to a limited extent throughout the fleet. The air-steam torpedo also is more suitable for discussion than are more advanced types because of security reasons.

An air-steam torpedo is divided into four main sections: head, air flask, afterbody, and tail. Internally, a fifth (midship) section is permanently joined to the air flask section.

MK 14 TORPEDO

Figure 12-3 shows the Mk 14 air-steam torpedo with principal contents of the main sections.

● The warhead, occupying the forward 4 feet of the torpedo, contains high explosive (HBX) and the exploder mechanism that detonates it.

● The air flask section (fig. 12-4) is the longest part (10 feet) of the torpedo, the air flask itself occupying most of the section. The flask carries the torpedo's air supply at a pressure of 2800 psi. Abaft the air flask is the water compartment, and inside the water compartment is a bulkhead that divides the air flask section from the midship section. The fuel compartment is in the center of the water compartment attached with brackets to the water compartment bulkhead.

● The midship section (fig. 12-3) contains a number of pipes that carry air, fuel, and water from the air flask section to the superheating system in the afterbody. A number of control valves are mounted on the shell of the midship section. Since this section contains many parts that carry the hot gases of combustion, there are holes cut in the shell of the section to allow sea water to flood and cool the parts therein.

● The afterbody (fig. 12-3) contains the torpedo's propelling and controlling mechanisms. These start the torpedo, generate and apply the power necessary to drive it from the time it is launched until it completes its run, determine the torpedo's vertical and horizontal courses, and maintain it on those courses throughout the run.

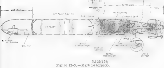
● The heart of the steering mechanism is the gyro. During the run, the axis of the spinning gyro remains rigid in space; that is, it points constantly in the same direction. If the torpedo turns off its set course, the gyro axis will still point in its original direction. That means that when the torpedo turns off course, the gyro will be in a different position relative to the rest of the torpedo. The steering mechanism detects this difference, and sends correcting orders to the steering engine. The steering engine then turns the steering rudders, to bring the torpedo back on course.

● Mounted on the outside of the tail cone are four fins, or vanes, which help to control the path of the torpedo during its run. Located on the after edge of the vertical fins are the two steering rudders, while both of the horizontal fins are on the after edge of the two depth rudders.

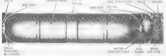
The torpedo propellers are mounted on the hollow sleeves at the end of the tail cone.

MK 16 TORPEDO

The Navy's only other air-steam torpedo, the Mk 16, is a single-speed torpedo that uses hydrogen peroxide (Navol) instead of compressed



3.126(158)
Figure 12-3.—Mark 14 torpedo.



4.62(110B)
Figure 12-4.—Air flask section of the Mk 14 torpedo.

air to supply the oxygen required for combustion of the fuel. Use of Navol rather than air allows the Mk 16 torpedo to carry a full load of explosive and to have greater high-speed range, without exceeding normal size.

The head section of this torpedo is similar to that described in the preceding paragraphs. The second or flask section contains a small compressed-air flask, a fuel (alcohol) tank, a water compartment, and a Navol tank—the last completely surrounded by the water tank. The main engine, valves, and control devices are located conventionally in the midship section and afterbody.

The source of the oxygen and of part of the water for the combustion cycle of these torpedoes is the Navol, which is a solution of hydrogen peroxide (H_2O_2) in water. Hydrogen peroxide, passing through a chamber containing a catalyst, decomposes with evolution of heat, to form water (steam) and oxygen. The oxygen unites with the fuel (alcohol) in the combustion pot, combustion being initiated by a conventional igniter. The resulting hot gases mix with steam and drive the main-engine turbines. Part of the steam comes from the breakdown of the H_2O_2 and part from additional water from the water compartment which is sprayed into the combustion pot to control the temperature.

By using Navol, the torpedoes require no air except (1) to force fuel, Navol, and water from their storage compartments to the combustion flask, (2) to drive the gyro, and (3) to operate the steering controls. As no air is fed to the combustion pot, no nitrogen is present in the exhaust to rise to the surface and leave the customary wake. There is, however, a small amount of nonsoluble gas resulting from the combustion of alcohol. This is forced out of the exhaust, leaving a very small wake that is practically invisible except in flat, calm water.

Some mods of the Mk 16 are capable of "pattern-running." This means that after a straight run of predetermined length on a preset course, the torpedo runs continuously at the same depth in horizontal circles of about 300 yards radius until the end of the run or until it hits a target. A control device in the torpedo (called an enabler) can be adjusted to vary the length of the straight part of the run (this is called the enabling run), at the end of which the enabler overrides the gyro steering gear and causes the rudders to steer the torpedo in a circle of fixed diameter. The torpedo can be set to circle to the right or to the left, as desired.

The pattern-running feature makes it possible for the torpedo to menace other ships near its target, if it should miss, and is therefore valuable when the torpedo is used in attacks on convoys. The torpedo can be set to run on a straight course only, if desired.

Note that pattern-running is not to be confused with the circular or helical search pattern

characteristic of homing torpedoes, as discussed below. Pattern-running torpedoes cannot home on targets. Unlike homing torpedoes, pattern-running torpedo exploders arm early in the enabling run. They initiate the war head charge either on contact with or in proximity to the target.

HOMING TORPEDOES

Non-homing torpedoes are designed to follow the course set on their gyro mechanisms, seek the specific depth set on their depth mechanisms, and run in a straight line without deviating (pattern-running torpedoes can also run in circles) until they run out of power. If on a warshot they fail to find a target, they sink.

During World War II, two new features were introduced into torpedo design. The first of these was electric propulsion, resulting in a wakeless torpedo which could not be visually detected from the vessel or target under attack. The second feature introduced completely changed the principles used to guide a torpedo, resulting in a "homing type" torpedo. The homing torpedo is guided by the sound of the vessel being attacked, or by reflected echoes.

A homing torpedo can follow a gyro course, but in general this is done only to get the torpedo to the vicinity of the target. The gyro-controlled run is then called an enabling run, and at the end of it the torpedo exploder is armed, the homing mechanism is activated to search for the target, and the influence device is set to function. The course taken by the torpedo after the enabling run is called the search pattern. The pattern may be helical, zigzag, circular, etc. It may include a fixed depth zone, or the torpedo may search from bottom to surface and back to bottom again. When the homing mechanism detects a target, the torpedo goes into its third stage of functioning — homing. It chases the target, and when it has come within effective range of the target, the influence mechanism operates the exploder to set off the main charge.

For security reasons, no homing torpedo can be discussed in detail here. We can only briefly discuss their principles.

At present, homing torpedoes are acoustic (operated by sound). In general, they are of two types — active and passive.

The active acoustic torpedo is not dependent upon the sound emitted from the target for its homing information. The torpedo itself generates and transmits the acoustic energy which is essential to its self-directing action. This energy, which has a fixed, controlled frequency and beam width, is reflected by the target in the same manner as sonar. The torpedo is designed to steer on a reflected echo, not on noises created by the target. The echo, after being received, is converted into electrical signals which control the operation of the rudder and elevator control surfaces, causing the torpedo to home on the target.

The passive acoustic torpedo homes on the noise emitted from the target. This noise, after being received by the torpedo, is converted into electrical signals which control the operation of the rudder and elevator control surfaces to steer the torpedo in the direction of the noise source.

The passive torpedo is effective only against targets which create or emit noise. It can often be evaded by the use of simple noisemaker type countermeasures which are used purposely to mislead or misdirect it. The target can also reduce its speed, or stop, in order to present a negligible noise source.

The homing torpedo has the same safety devices as the air-steam type. Its exploder is armed both mechanically and electrically, and remains safe until the torpedo has traveled a safe distance from the firing ship. The homing mechanism also has an arming feature, that keeps it inoperable (with the torpedo on a gyro course) until the torpedo has traveled through a preset enabling run distance. One or more additional safety features not found in nonhoming torpedoes are present in all homing torpedoes.

Homing torpedoes, almost without exception, are powered by electric motors and batteries. In shape and external appearance they are quite similar to the nonhoming torpedoes already described. Most types are somewhat smaller than air-steam torpedoes, in length, diameter, or both. And several types have a single propeller, rather than two.

Homing torpedoes may be launched with or without torpedo tubes. Many homing torpedoes are electrically set; others are preset (i.e., they are dropped in the vicinity of the target, seek the depth set in advance, and go into the preset search pattern without going through the enabling run stage).

The following are brief descriptions of homing torpedoes currently in service:

- The Mk 37 torpedo is electrically controlled and propelled two-speed torpedo with an active-passive acoustic homing system. This torpedo, launched from submarines or destroyers, is effective against either surface or submarine targets. It is launched from above water tubes as an air-ejected torpedo or from submerged tubes as a swim-out torpedo. Some mods are wire guided, making them invulnerable to several enemy countermeasures.

- The Mk 44 torpedo is an electrically controlled and electrically propelled antisubmarine weapon, with an active acoustic homing system. The torpedo can be launched from surface craft or aircraft and is the torpedo payload for Asroc (see chapter 13).

The torpedo is designed to attack submerged submarines traveling at moderate speeds. After enabling, the torpedo searches for a target by active acoustic means while maneuvering in a helical path. Echoes from the target cause the torpedo to steer toward the target until contact is made. If the torpedo loses the target, it searches for a short time in the general direction in which it is traveling and, if unsuccessful in relocating the target, resumes a helical search.

The acoustic homing system of the torpedo also has a passive feature that allows the torpedo to respond to an acoustic noise source whose frequency level is within the sensitivity range of the receiver. During the torpedo's normal search pattern, passive homing on a target noise source aids in target acquisition, increasing the attack capabilities of the weapon.

- Torpedo Mk 45 is the torpedo payload for Astor (antisubmarine torpedo), which also is configured to carry a nuclear warhead. Electrically powered, it may be set for straight runs, or it can be wire guided against submarines or surface ships. Astor can be launched by all nuclear and some conventional (hunter-killer) submarines.

- The Mk 46 torpedo originally was to have been the successor to the Mk 44. The principal difference between the two is the improved propulsive power of the Mk 46, which gives it greater speed, range, and depth capabilities.

TORPEDO TUBES

Torpedo tubes serve the following purposes:

1. House and protect the torpedo (including heating in cold weather) until the instant of firing.

2. Provide means for setting torpedo gyro angle, running depth, etc., as necessary, up to the instant of firing.

3. Expel the torpedo with sufficient force to clear the firing ship, and with such velocity and direction that it will remain on its firing course until its engine develops enough power for self-propulsion.

4. As expulsion starts, trigger the torpedo so as to start its engine and gyro.

These functions apply to submarine tubes as well as above-water tubes. Since, however, the former must also serve as pressure members of the ship's hull, they incorporate additional features which are beyond the scope of this text.

SURFACE TUBES

Above-water tubes may be classed as trainable or fixed. Functionally their performance is similar, but there are structural differences. Fixed tubes are usually mounted so that their muzzles protrude through a bulkhead or some part of the ship's hull. Trainable tubes require large clear deck areas, and in all ships that carry torpedoes they are mounted topside in some such location as the weather deck. From this location torpedoes can be fired through limited arcs of train on both sides of the ship.

During World War II standard destroyer-type ship armament included one or two quintuple (5-barrel) torpedo tubes. A black-powder impulse charge was used to expel the torpedo from the tube in launching. With all tubes loaded, the vessel had 10 torpedoes, plus spares. The torpedoes were all of the conventional air-steam type described earlier in this chapter, normally had impact exploders, and were fired either singly or in salvo against targets. Homing torpedoes, then in an early stage of development, were not a standard part of destroyer armament, and the use of homing torpedoes by surface craft against submerged submarines was not a standard part of U.S. naval doctrine.

Beginning late in World War II and continuing thereafter, this arrangement of deck-mounted quintuple tubes became obsolescent. One cause of this was the need for increased AA armament, which put a premium on topside deck space. After World War II, destroyer-type ships were

fitted with but one quintuple tube mount, and the conventional torpedo load was reduced from 10 to 5. At the same time, newer designs for destroyer and escort craft had torpedo tubes mounted in above-water locations other than the weather deck. In such locations, the tubes had to be housed and fixed (i.e., nontrainable).

With fixed tubes, greater gyro angles must be used in firing than from trainable tubes; and, since torpedoes tend to depart more widely from their predicted courses when fired with large than with small gyro angles, this is a disadvantage. Also, tubes must be carried on both sides of the ship. However, the weight advantage gained by eliminating the training gear, pivots, etc., provides a partial compensation. The interior location permits all tubes to be located in the same compartment of the ship, in which reload torpedoes and quick-reloading gear may also be carried. The newer tube designs use compressed air instead of impulse charges to fire the torpedoes, and are usually fitted with electrical accessories necessary for firing electrically-set torpedoes, including homing types. With the advent of the homing torpedo, the role of the surface-launched torpedo began shifting from surface targets to submerged targets. Today, torpedoes and their launchers are primarily designed for use against submarines.

Figure 12-5 represents a single-barrel, fixed-type, non-trainable torpedo tube designed to mount singly or in groups of two or more on each side of a ship. The tubes, constructed of a light-weight aluminum alloy, are mounted athwartship within the superstructure, with muzzles extending through the sides of the deck house. The torpedoes are ejected by a blast of compressed air. The tubes are suitable for launching only torpedoes having electrically set torpedo controls. They were designed to launch 21-inch torpedoes, although adapter rings have been supplied to permit launching a 19-inch diameter torpedo.

There are several versions of the Mk 32 trainable torpedo tube assembly (fig. 12-2). One version is designed to operate with compressed air from the ship's supply; another uses an air bottle and is installed on craft that have no other air supply available. These two are otherwise similar, and are designed for mounting on the weather deck.

Each tube assembly consists of three separate and independently operated barrel, mounted on a common training gear. The barrels and training gear are equipped with thermostatically controlled electric heating units for cold weather operation. Each barrel is fired independently, usually by an electric firing circuit, although manual firing is possible for emergencies. The mount can be trained through 190° by manually cranking a worm that engages a worm gear.

The barrels are arranged in a triangular group, with a pair below surmounted by the third above and between them as shown in figure 12-2. Each barrel is fabricated of Fiberglas reinforced plastic. The breech mechanism covers one end of the tube, and the muzzle cover is at the other end. Along the top surface of the tube are two access openings (called the large and small cover assemblies)—one toward the muzzle, the other toward the breech. The openings are used for attaching lanyards to the tube for starting the torpedo and for enabling the exploder to arm. The electrical plug used to

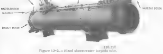
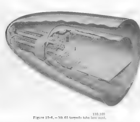


Figure 12-5.—Fixed above-water torpedo tube.



110.160
Figure 12-6. — Mk 65 torpedo tube bow nest.

set signals into the torpedo before launching is located under the breechward cover.

The muzzle cover is a Fiberglas reinforced plastic assembly with a rubber ring which helps to lock the cover closed. The breech mechanism consists principally of a rubber-lined reinforced Fiberglas plastic air flask with controls, valves, and fittings on it. It is bolted in place. The tubes are loaded through the breech end. The firing valve in the breech mechanism releases a blast of compressed air into the after end of the tube to eject the torpedo.

A waterproof aluminum control box contains the solenoid-actuated air valve which controls firing. Buttons protruding from the after side of the box provide for either electrical or manual actuation of the valve. A junction box houses the connection between the ship's supply and the electrical heating systems of the barrels and training gear.

Current mods of the Mk 32 launcher are designed to handle the latest homing torpedoes. A nontrainable version of the Mk 32 consists of two barrels, one over the other, and is installed in a deckhouse with the muzzles extending through the bulkhead.

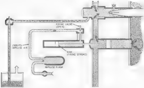
SUBMERGED TUBES

Submarines fire torpedoes from fixed tubes located in the bow, both bow and stern, or amidships.

Older tubes ejected weapons pneumatically by means of compressed air. Newer tubes utilize hydraulic ejection—launching by means of a charge of water. The latter method results in a quieter and bubbleless ejection.

Component parts of submerged tubes are basically the same as surface tubes. There are differences, of course, in tube function and operation. For purposes of discussion, this brief coverage will be confined to the Mk 65 bow tubes.

Bow tubes are referred to as the bow nest. The Mk 65 installation consists of four tubes in two vertical banks (as in fig. 12-6), one port and one starboard of, and parallel to, the ship's



110.161
Figure 12-7. — Method of ejecting a submerged torpedo.

centerline. Each tube can be loaded, flooded, fired (locally or remotely), and drained separately from the others. The tubes penetrate the pressure hull at an angle of 10° from the centerline. Weapons can be launched while the submarine is either submerged or surfaced.

In addition to the usual tube features such as barrel, breech door, and muzzle door, a submerged tube has the following basic components: (1) water 'round torpedo (WRT) tank, (2) blow-and-vent air connections to the tube and WRT tank, and (3) flood-and-drain water connections to the tube and WRT tank.

Rather than dwell on specific tube characteristics, following is a simplified version of what happens to a submerged torpedo tube during basic operations of loading, flooding, ejection, and draining. No attempt is made to include a technical description of the functions of the associated valves, interlocks, and other controls that must be operated.

1. Loading: Before a tube is loaded, it is checked to be sure it is vented (vent valve open to permit escape of air) and free of water. The breech door is then opened by hand and the torpedo is moved from handling tray into tube. The breech door is shut and locked. The ejection pump sea valve is opened (to admit sea water to the ejection pump water cylinder), and the impulse flask is charged with compressed air.

2. Flooding: After loading, water is blown from the WRT tank through an open flood-and-drain valve into the vented tube until the tube is flooded. Tube pressure and sea pressure are then equalized and the muzzle door opened. The tube now is ready for firing (ejection).

3. Firing: Firing (fig. 12-7) causes the firing valve to open, admitting compressed air from the impulse flask into the ejection pump air cylinder, forcing the ram aft. The piston on the seaward end of the ram forces water into the tube abaft the torpedo. Water pressure then forces the torpedo out the tube muzzle and the ram returns to battery.

4. Draining: After firing, the muzzle door is shut and water in the tube is blown (or drained by gravity) through the tube drain valve to the WRT tank. The tube then is vented.

36.2
Figure 12-8. — Confederate harbor mine.

55.3
Figure 12-9. — World War I mine and North Sea barrage.

MINES

The Dutch broke the Spanish Blockade of Antwerp in 1585 with what was probably the first floating mine. They called it an "explosive vessel." It was no more than an old ship loaded with gunpowder and ignited by a clockwork-operated flintlock. The British, with the largest fleet in the world at the time, were the first to suffer casualties by the first real mine that was used.

During the American Revolution David Bushnell attempted to break the British blockade of the Delaware River at Philadelphia with floating kegs filled with gunpowder and equipped with contact-firing devices.

Robert Fulton also contributed to mine warfare by proving that a ship has little resistance to an underwater explosion. By the time the American Civil War came along, mines were considered a prime naval weapon. During this war, 27 Union ships were sunk by mines while only 9 were destroyed by gunfire. Figure 12-8 shows a Confederate mine. At the entrance of Mobile Bay, Admiral Farragut shouted, "Damn the torpedoes — full steam ahead!" He was referring to what we now know as mines, not torpedoes.

Mines were considered only a defensive weapon until the Russo-Japanese War of 1904. The Japanese almost destroyed the entire Russian fleet by luring them into mined waters. This development opened up a new use for mines, although it was not until World War I that offensive use of mines came into being.

During World War I, the allies bottled up the German U-boats in the North Sea by laying a minefield from Scotland to Norway (fig. 12-9). This allowed the allies to use Atlantic shipping routes in comparative safety. Contrary to popular belief, there were more ships sunk by mines than by torpedoes and gunfire combined during World War I.

After World War I there was a slump in mine warfare development. During the period between the two world wars, new mines were designed but not developed to any great extent. At the outbreak of World War II the Germans used a magnetic mine very successfully. Our magnetic mechanisms were so crude that we copied a German device which the British had taken from a captured mine. Since 1940, mines have developed into very complex weapons that have several methods of planting and several ways of being detonated.

Again in World War II, during Operation Starvation (the blockading of Japan), mines sank more enemy ships than all other types of weapons combined. This operation was so successful that it almost stopped Japanese shipping completely. A side effect of this was that civilian morale

56.4

Figure 12-10.—Surface-craft-planted mines.

was broken because Japan could not import enough food. This was the United States' largest and most successful use of offensive mining.

Probably for this reason, mine development has not slackened as it did after World War I. This makes it difficult to keep up with the development of new mines and modifications to the old ones. A detailed discussion of the various mine marks and mods used today is beyond the scope of this unclassified text.

MINE CLASSIFICATION

Mines are classified by types according to (1) the method of planting, (2) the mine's position in the water, and (3) the method of actuation (firing).

Classification by Method of Planting

Method of planting means the method by which mines are put into the water. There are three classifications of mine according to methods of planting: (1) surface-craft-planted, (2) submarine-planted, (3) aircraft-planted.

Mines can be planted by surface craft (fig. 12-10) when secrecy is not of prime importance. High speed minelayers are usually used to do the job. A minelayer can carry a large number of mines, and can lay a large minefield in a relatively short time. Presently, the Navy has no minelayers in commissioned service. In case of war, however, these ships could be reactivated in a short time.

Submarine-planted mines (fig. 12-11) have an advantage over surface-craft-planted mines in that the mining operation can be accomplished with great secrecy, and at great distances from home ports. One of their disadvantages is that once an area has been mined, it must be avoided for the armed life of the mines. Therefore submarines cannot repeatedly mine the same area.

Aircraft-planted mines may be carried on the aircraft internally or externally, like bombs or torpedoes. Aircraft can carry mines into enemy-held areas, and the field can be replenished over a long period of time without danger from previously planted mines. There can be no secrecy in planting this type of mine, but aircraft can plant mines in enemy-held shallow coastal waters that cannot be mined by other means. Blockading of enemy shipping lanes can be very effectively accomplished by this type of mining.

Although each mine is designed for planting by a particular method, and is so identified, aircraft- and submarine-planted mines may also be planted by surface craft when appropriate adaptations have been made. For limited operations, almost any ship or boat can be adapted to plant mines. This flexibility makes all types of mines available for surface planting.

Classification by Position in the Water

By their position in the water, mines may be divided into two categories—moored and bottom.

The moored mine (fig. 12-12) has a bouyant case containing an explosive charge. The case is kept at a predetermined depth by a chain or cable attached to an anchor. This type mine may have either a contact- or influence-firing mechanism. Its main disadvantage is that it may be cleared with comparative ease by mechanical minesweeping gear. (It was for this reason that the bottom mine was developed.) The two most important advantages of the moored mine are: (1) it can be moored close to the surface so that it will be actuated by any ship or boat, no matter how small, that penetrates the minefield, and (2) it may be planted in waters that are too deep for bottom mines, since the case of a moored mine assumes a position some distance from the bottom. The maximum depth of water in which a moored mine can be planted is limited by the downward pull on the case caused by the weight of the cable and by the drag of tides and currents.

The bottom mine (fig. 12-13) is held on the ocean's bottom by its own weight. It can be planted by surface craft, submarines, and aircraft; but normally surface craft are not utilized to plant bottom mines. This type of mine generally is not effective against surface ships when planted in waters more than 30 fathoms deep. They may be planted in deeper water, however, as antisubmarine weapons. Because this type of mine lies on the bottom, the enemy must use costly minesweeping gear to detect them. Also, the bottom mine is more difficult to detect with locating gear than the moored mine, especially when it lies in soft mud or on a densely growth-covered bottom.

Classification by Method of Actuation

The third way of classifying mines is by the type of firing mechanism or device used to actuate them. The classification is subdivided into (1) contact and (2) influence mines.

CONTACT MINES.—Contact mines are fired by actual contact of the mine case or its attachments with the hull of a ship or any such target. Typical contact-firing devices are switch horns, inertia switches, tension-firing mechanisms, and galvanic action or chemical horns.

When the switch horn comes in contact with a ship, it mechanically closes, firing the mine. An inertia switch also closes a switch when the ship contacts the mine. A tension-firing mechanism is used only in a mine that destroys enemy sweep gear and fires the mine when the sweep cable pulls up against it. The galvanic action type operates on the principle of the wet cell battery. A steel ship comes in contact with a horn or antenna on the mine, forming a sea cell. The weak current from this sea cell goes to the firing mechanism, initiating the firing of the mine.

The chemical horn also operates on the wet cell battery principle. When a horn is bent, a vial is broken releasing acid to a wet cell battery. The current from this battery fires the mine.

INFLUENCE MINES.—Influence mines are much more complex than contact mines. They are fired by the close approach or passing of a ship. Bottom mines are of the influence type. This type uses several different means of actuation. It may be actuated by (1) sensitivity to

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Figure 12-11. — Submarine-planted mines.

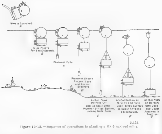

Figure 12-12. — Sequence of operations in planting a Mk 6 moored mine.

the target ship's magnetic field, (2) by sensitivity to the ship's underwater sound, or (3) by sensitivity to the reduction of water pressure around the mine caused by the passing of a ship. We have mines which may use only one of the above means of actuation, but we also have mines which use a combination of all three. The influence mines have a larger target width, and are much harder for the enemy to sweep than the contact mines. In fact, with combinations of firing mechanisms, the influence mine can be made almost impossible to destroy with minesweeping gear. A brief discussion of the different types of influence mines follows.

Magnetic Mines.—The magnetic mine is actuated by a change in the earth's magnetic field surrounding it. A steel ship intensifies the earth's normal magnetic field. This change in magnitude or direction of the field, if in the proper sequence, will actuate the firing mechanism. The magnetic firing mechanism is of the magnetic induction type.

The magnetic induction mechanism operates on the change of magnetic field of the mine. This mechanism depends primarily on the rate at which the field intensity changes, rather than on the amount of change. A small current is induced in a coil by the changing field. If sufficient potential is developed, a relay is actuated, closing the firing circuit. This type of mechanism is used in bottom mines, in areas where ships are under way at normal speeds.

Acoustic Mines.—The acoustic mine operates on the noise produced by a ship's propeller(s),

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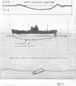
Figure 12-13. — Bottom mine.



56.7
Figure 12-14. — Pressure signature.

engines, and hull. A microphone converts these sound vibrations into electrical impulses, which are fed into an amplifier. The mechanism will actuate only when it receives sound impulses of proper intensity, rate of change of intensity, frequency, and duration. If the noise does not meet the above specifications the mechanism will not actuate, thus protecting the mine from random underwater noises. This mechanism, like the magnetic induction mechanism, is used in bottom mines.

Pressure Mines. — This mine's firing mechanism is actuated by the change in water pressure caused by a moving ship. A passing ship momentarily increases the pressure as the ship's bow wave passes. This increase is followed by a reduction in pressure for a sustained period (fig. 12-14). Contrary to popular belief, it is this reduced pressure, rather than increased pressure, that operates the mechanism. This mechanism is used only in bottom mines, and only in areas where ships are under way at normal speeds. The pressure mechanism is probably the most difficult to sweep.

Combination Mines. — A combination of mechanisms improves the usefulness of a mine in that it is less likely to be actuated by false targets. Also it makes the mines harder to sweep. For the mine to fire, all the incorporated firing mechanisms have to be actuated within a specific time limit. The first mine of this type was pressure-magnetic. It was first used as an aircraft-planted bottom mine and later as a submarine-laid bottom mine. We now have mines that use a combination of all three types of firing mechanisms at one time. Once again, this improvement makes mines of this type almost impossible for the enemy to sweep.

LIFE CYCLE OF MINES

The life cycle of a mine follows the same pattern as that of a living thing. It can be said that a mine is born when it is planted, and lives for the armed life set for it. It dies when it is exploded, or when it is rendered safe by the sterilizer device. Because much of the life cycle is the same for all mines, only one contact type and one influence type will be discussed.

The Mk 6 surface-craft-planted, moored, contact mine is carried on the launching rails of the planting ship (fig. 12-10), on wheels attached to the mine anchor. After the area to be mined is reached, shipping safety features are removed from the mine. When the order is received to plant a mine, the launching crew rolls a mine off the stern of the ship. After the mine is in the water, its case and anchor separate, as in figure 12-12. The anchor sinks to the bottom, and the case finds its mooring depth. At this time the mine cannot be detonated, because of safety features designed to protect the planting vessel. After a predetermined time the mine is armed, and will blow up when any ship comes in contact with it. Mines are designed to render themselves safe after the usefulness of the minefield has lapsed. This safety feature is necessary because it is unlikely that all of the mines in a field will be actuated by enemy ships, and we may later want to use the area for our own ships.

An influence mine is mounted on or in an airplane at its home base. At the proper time the plane will carry the mine to the area to be mined, and drop it as it would a bomb. The mine has a parachute attached which slows it as it drops. When the mine hits the water, the parachute separates from the case, and both case and parachute sink to the bottom. The delay arming safety features start operating to arm the mine. Like the contact mine, this mine can be actuated by any ship, but in the case of influence mines, the ship has to meet certain specifications to actuate the firing mechanism.

MAJOR MINE COMPONENTS

The major components of a mine are the case, the explosive filler, the anchor (if one is used), and the firing mechanism with its accessories.

The mine case provides a watertight compartment for the main charge and the firing system. The bursting charge occupies the main compartment, and in bottom mines will fill most of it. In moored mines, the case must be large enough to provide air space for buoyancy. Smaller compartments in the case house and secure the batteries, firing mechanism, and accessories.

Mine cases are usually made of steel, but a nonferrous metal is required when certain influence firing mechanisms are to be used.

Anchors for various moored mines naturally differ in size, shape, and method of operation. All must be capable of mooring the mine at a preset depth below the surface. For ease in handling, the anchor is assembled integrally with the case.

The operation of the anchor assemblies during planting of a typical moored mine is illustrated in figure 12-12. Note that this surface-laid assembly has a net positive buoyancy until the case and anchor are separated, flooding the anchor. Conversely, aircraft-planted or submarine-planted assemblies, which are employed in offensive mining operations in enemy waters, have a net negative buoyancy and never reach the surface after planting.

Most of the standard naval mine cases will accommodate a choice of explosive fillers and a choice of the various firing systems and accessories. Because of this, the mark designation of the mine usually applies only to the assembled case and anchor. On the other hand, a specific modification of a production mine usually designates its explosive filler, firing systems, accessories, and the special features which adapt this mine to surface, submarine, or aircraft planting.

MAJOR MINE ACCESSORIES

Mines utilize many separate units to increase their effectiveness. Some of these accessories are safety devices; others increase the efficiency of the planted mine. A few of the more important mine accessories are defined briefly in the following paragraphs.

1. The EXTENDER mechanism is a hydrostatically operated device used to hold the mine detonator a safe distance from the booster charge until the mine has been planted.

2. HYDROSTATIC SWITCHES are used to close electric contacts by means of hydrostatic pressure working against spring pressure.

3. The ARMING DEVICE is an extender and hydrostatic switch assembly which aligns an explosive train and operates electrical contacts when subjected to hydrostatic pressure.

4. The CLOCK STARTER mechanism is a hydrostatically operated device used to start the clock delay mechanisms when the mine sinks to a preset depth.

5. CLOCK DELAY mechanisms delay the arming of the mine for a preset time after planting. This allows the planting craft time to plant a large minefield before the mines become

dangerous. Clock delays are also used to stagger the arming of mines in a field to improve its effectiveness. Clock delay mechanisms are of two basic types; hand wound and motor wound. Hand-wound clocks may be set to provide a delay in arming of 1/2 to 10 days; motor-wound clocks provide a delay of 3 to 100 days.

6. The STERILIZER mechanism is used to limit the armed life of a mine to a predetermined time. It renders the mine inoperative by shorting out the battery, or in some cases by opening the detonator circuit.

7. BATTERIES used in mines are of the dry cell type. Each is composed of several cells arranged in a waterproof container. The batteries provide the required voltages and current to operate the mine accessories and the firing system to fire the detonator at the proper time.

8. The ACTUATION COUNTER (sometimes called a ship's eliminator or ship's counter) is designed to delay firing the detonator until the firing mechanism has completed its operation a predetermined number of times.

9. SEARCH COILS are used in magnetic induction mines to detect changes in the earth's magnetic field around the mine.

10. The MICROPHONE or HYDROPHONE contains a crystal which changes sound energy into electrical energy to actuate the acoustic firing mechanism.

11. CONTROL BOX is a device which performs switching and timing functions. It ensures that certain requirements are met before the mine will fire.

12. SENSITIVITY SWITCHES are provided to adjust the sensitivity of the firing mechanism of a mine for best use against an intended target.

13. HYDROSTATIC RELEASES are mechanisms used to release a device from a mine, or to separate two cables at a predetermined depth.

14. PARACHUTE PACKS are metal or plastic-and-canvas containers holding a parachute which is used to reduce the impact velocity of an aircraft-laid mine when it enters the water. This protects other mine accessories from damage that would result if the mine were allowed to fall freely and strike the water at high speed.

TYPES OF MINEFIELDS

The subject of minefields is a very extensive one, and space is not available in this text to cover it fully. More detailed information can be found in the current edition of NWP 26.

A mine is designed to do the same job as a gun projectile or torpedo. The big difference is that mines are rarely used one at a time; a group of mines is used to make up a minefield. The two main purposes of these fields are first, to destroy or disrupt enemy shipping—both combatant and noncombatant; and second, to protect United States and Allied shipping and Allied controlled territories.

The type of field in which mines are planted is dictated by the prevailing situation. The choice of field type is an application of the potentialities of mines and planters to the problems which the situation presents.

Minefields may be divided according to purpose into two broad groups—defensive and offensive—with variations to make them more effective.

Defensive Minefield

A defensive minefield is similar to a defensive football team in that they both try to hold back the opposition. Although defensive mining usually attempts to keep the enemy guessing at all times, in some cases the field is well advertised. This adds to the effectiveness of the field, because the enemy may decide against entering these waters due to the potential danger. The area may still be utilized by our forces and Allies provided with charts showing the mine-free navigable channels. Some of the specific ways in which mines may be used defensively are as follows:

1. In large harbors and anchorages for permanent harbor defense.
2. To protect advance base anchorages.
3. To protect assembly points for convoys.
4. To protect coastal shipping lanes from seaward attack.
5. As a submarine trap.
6. As anti-invasion fields.

Offensive Minefield

The offensive minefield—in keeping with our analogy—can be compared with a football team on the offensive; they both take the action to the opponent. These fields are planted in enemy-held or disputed waters to disrupt enemy shipping.

Offensive minefields do this by destroying or damaging the enemy's ships, or by making areas unusable because the threat of losses is so great.

Offensive fields are subdivided into two groups—uncountered attrition and countered attrition on fields. Uncountered fields are those which the enemy is not expected to counter by minesweeping or hunting, and which are intended primarily to cause damage to enemy ships. Countered attrition fields are of two types: transitory fields and sustained attrition fields.

TRANSITORY ATTRITION FIELDS.—Transitory attrition fields are small, secretly planted fields laid in an area in which traffic is sufficient to give a reasonable probability of a casualty. From the meaning of transitory, obviously this field is designed to last only a short time. The field can be swept easily or avoided by the enemy, and mines that are destroyed are usually not replaced.

SUSTAINED ATTRITION FIELDS.—Sustained attrition fields are laid where they cannot be easily avoided by enemy traffic. They are maintained for a prolonged period of time by replacing mines which have been blown up. If the casualty rate is so high that the enemy cannot afford the losses, the minefield can deny them the use of the channel or area.

Mines are an excellent STRATEGIC weapon in that mining operations can be carried out over a prolonged period without regard to other military activities. Mines destroy the enemy's war-making potential behind their own lines. On the other hand, a mine is a poor TACTICAL weapon because of the lengthy and detailed preparation necessary for planting a minefield. A tactical weapon is one designed for supporting or protecting a single engagement, and time usually does not permit the use of mines for this purpose.

The design of a minefield depends on the purpose of the field and on the countermeasures expected. They are divided into six types:

1. Countered fields are those which the enemy is expected to counter by minesweeping or hunting.
2. Uncountered fields are those which the enemy is not expected to counter by minesweeping or hunting.
3. Protective fields primarily protect what lies behind the field by hindering or preventing the enemy's approach.
4. Attrition fields are those intended primarily to cause damage to enemy ships.
5. Nuisance fields are those where a few mines are laid to harass the enemy.
6. Dual Purpose fields are those having more than one purpose.

MINELAYING

A sudden massive attack by minelaying aircraft is considered to be one of the greatest threats to any maritime power that exists today. So great, in fact, that the possibility of such an attack requires major expenditures of manpower and equipment in conducting counter-measure operations, whether a single mine has been laid or not.

Offensive minelaying by surface craft has comparatively limited application in enemy-held waters. The utmost secrecy can, of course, be obtained by laying mines from submarines. However, a submarine cannot replenish the interior of an existing minefield without itself being exposed to an unacceptable amount of danger. That brings us to the use of aircraft. The aircraft naturally leads in its ability to lay mines suddenly and in great quantity. It is, further, as mentioned earlier, the only craft capable of replenishing a large existing field without danger from the field itself. Offshore shipping lanes can be mined by bombers and patrol planes whenever the depth of water is not too great. Mining of enemy-held rivers and harbors would generally be effected by tactical aircraft under conditions of low visibility or under cover of diversionary raids.

MINE COUNTERMEASURES

Mine countermeasures include all actions taken primarily to protect own or friendly shipping against mines, including (1) reducing the effectiveness of enemy mines, and (2) clearing areas mined by friendly forces, after those areas have served their purpose. The three major types of mine countermeasures are ship treatment (against magnetic and acoustic mines), mine hunting, and minesweeping.

Ship Treatment Against Magnetic Mines

There are two principal methods (deperming and degaussing) of treating a steel ship hull to

decrease the magnetic effects that actuate magnetic mines. Before taking these up, let us consider in more detail the characteristics of a ship's magnetic field.

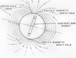
Any ship's magnetic field can be analyzed into two main components — its permanent field and its induced field.

PERMANENT MAGNETIC FIELD. — When a ship's hull is being fabricated in a shipyard, it is subjected to heat (welding) and to impact (riveting). Ferrous metal contains groups of iron molecules called "domains". Each domain is a tiny magnet, and has its own magnetic field with a north and south pole. When the domains are not aligned along any axis, but point in different directions at random, there is a negligible magnetic pattern. However, if the metal is put into a constant magnetic field and its particles are agitated (as they would be by hammering or by heating), the domains tend to orient themselves so that their north poles point toward the south pole of the field, and their south poles point toward the north pole of the field. All the fields of the domains then have an additive effect, and a piece of ferrous metal so treated has a magnetic field of its own. You can demonstrate this by hammering on an unmagnetized piece of steel such as a knife blade in a strong magnetic field; the steel will develop a permanent field. The effect occurs (though to a lesser extent) even if the magnetic field is not strong. Although the earth's magnetic field is not strong, a ship's hull contains so much steel that it acquires a significant and permanent magnetic field during construction.

INDUCED MAGNETIC FIELD. — Imagine a magnetic field as consisting of many tiny "lines of force"[1] — running from the magnetic north pole to the magnetic south pole of the field in a closed loop. The earth has such a field, as if it contained a huge bar magnet (fig. 12-15). The magnetic poles do not coincide with the geographic poles, however. Visualize an area of the earth's surface, with the invisible magnetic lines of force more or less evenly distributed over it. Air and water have low magnetic permeability — that is, they do not conduct magnetic lines of force (or magnetic flux) especially well. Now put a ship's hull into the sea at the point being considered. Ferrous metal has relatively high permeability. The high-permeability hull distorts the field because the magnetic lines of force tend to concentrate in it. If the ship is pointed toward magnetic north, the effect is as shown in figure 12-16, part A; if the hull is pointed eastward, the effect is as shown in part B of the figure.

This distortion of the earth's magnetic field (by concentrating part of it in the magnetically permeable hull) is the induced field. As figure 12-15 shows, however, the magnetic lines of force of the earth's field are not parallel to the earth's surface except in the vicinity of the equator. Elsewhere they are tilted with respect to the surface; at the magnetic poles they are perpendicular. The induced field therefore has a vertical component as well as a horizontal. The strength of the vertical component is affected chiefly by the ship's location on the earth with respect to the magnetic poles. Figure 12-16 illustrates the latter effect.

DEPERMING. — The purpose of deperming is not to eliminate a steel hull's permanent magnetic field altogether (this is not practical on a large scale), but to (a) reduce it to a minimum, and (b) make it more or less similar



27.104
Figure 12-15. — The magnetic field about the earth.

[1] The idea of "lines of force" is intended only as an aid in thinking of the effects of magnetic fields. Their existence has not been physically demonstrated, and the idea should be considered only as a conceptual convenience, not as a physical fact.

A B

27.105:56.29
Figure 12-16. — A ship's hull distorts the earth's magnetic field.

to others of the same hull type. At a number of locations called magnetic or degaussing ranges, magnetic sensing devices located on the bottom of a channel can detect a ship's magnetic field pattern as it steams past. The recording made of the ship's magnetic pattern is called its magnetic signature. After deperming, a ship's permanent magnetic field has not only been reduced to a practicable minimum, but its signature is similar to that of other depermed ships of the same class. The degaussing installation (described below) can then be set up on a "mass production" basis. The deperming process cannot be described here in detail: suffice it to say it is essentially a large-scale version of the process for demagnetizing a watch.

DEGAUSSING. — The purpose of degaussing is to counteract the ship's magnetic field so that (ideally) the magnetic field near the ship is the same as it would be if the ship weren't there. To some extent this can be done by magnetic treatment of the ship using coils temporarily installed. This is not as effective as the more frequent method — using permanently installed equipment, as follows:

1. Degaussing coils.

2. A d-c power source to energize the coils.

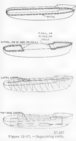
3. Means to control the currents in the coils.

4. Magnetic compass compensating equipment to cancel out the disturbing influence of the degaussing equipment on the magnetic compass.

Degaussing cannot be exhaustively described in this text. The interested student is referred to the NavShips Technical Manual. The term "degaussing" is derived from "gauss," the unit of magnetic field strength (in turn, the name of this unit commemorates the German 19th-century mathematician Karl Friedrich Gauss). We can cover here only some high points.

The ship's magnetic field (permanent plus induced) can be analyzed into 5 components. The degaussing installation is designed to produce as accurately as possible an exactly opposing field. This is done by encircling the hull or other parts of the ship's structure by coils of heavy electric cable. The coils are designated as M (main coil), F (forecastle), Q (quarterdeck), L (longitudinal), and A (athwartship). See fig. 12-17. Various combinations of these are energized as required to create the desired fields. The coils are excited either by the ship's d-c supply or by a motor-generator which produces the direct current required. The polarity and current in each coil may be manually controlled, but the present trend is to make the functioning of the system completely automatic, except for manual setting of magnetic latitude and magnetic variation (i.e., difference between the direction to the geographic pole and to the magnetic pole). Such a system may compensate for ship's heading only, or for heading, roll, and pitch, by using servos to vary the d-c inputs to the coils.

Effective though deperming and degaussing are, residual magnetic fields accompany all steel-hull ships, especially larger ones. For such critical work as minesweeping, more drastic



27.107
Figure 12-17. — Degaussing coils.

antimagnetic measures are necessary. Minesweepers therefore may be built with nonmagnetic hulls to reduce magnetic effects to the vanishing point.

Ship Treatment Against Acoustic Mines

Acoustic mines function in response to the underwater sound output of ships. Most underwater noise of ships is caused by movement of the screw blades with respect to the water. At high screw speeds parts of the screw move so fast the water cannot flow around the screw edges fast enough, causing low pressure areas to form, then collapse. These actually are cavities or bubbles of water vapor, and their rapidly repeated formation and collapse produces water vibration at sonic or subsonic frequencies. Other causes of ship noise are vibration of external parts in the water as the ship passes through, water flow over sharp surfaces or obstruction of the hull, and transmission through the hull, screws, and screw shafting of machinery noises to the water.

The only important design change that could materially change acoustic disturbances caused by ships would be the development of a screw shape that would reduce cavitation or cavitation noise at high speed. Research is now under way on this. For the rest, once the ship's hull has been adequately faired, little can be done so far as design is concerned to reduce acoustic noise output. Noise can be reduced only by reducing screw speed, shutting down noise-producing machinery such as reciprocating pumps, etc.

Minehunting

The methodical detection, location, and neutralization of mines is appropriately called mine hunting. Some craft and their highly trained personnel specialize in this work.

The shipboard devices used in mine detection are called ordnance locators. The sensing component of an ordnance locator is called an ordnance detector. The term ordnance detector can also refer, however, to a small, man-carried ordnance locator in its entirety.

Minesweeping

Minesweeping is accomplished by going over a mined area with mechanical sweeps that physically remove the mines (for example, by cutting mooring cables of moored mines) and with influence sweeps that provide the influence fields necessary to actuate influence mines. In addition to minesweeping ships and crafts, helicopters can be used to sweep mines in some instances.

SWEEPING MOORED MINES. — The Navy uses several types of sweep gear for sweeping moored mines. In the most common type, a wire cable (sweep wire) is towed through the water deep enough to strike the mine mooring. The mine mooring then slides along the sweep wire until it engages one of several cutters spaced at intervals along the sweep wire. The cutter severs the mooring, and the mine bobs to the surface where it can be detonated or sunk by

gunfire. The sweep gear can be streamed to both sides of the ship simultaneously.

Minesweeping cutters are either mechanical or explosive. A mechanical cutter has no moving parts and cuts the mine mooring by means of two saw-toothed blades in the form of a V. It will cut wire moorings up to 1/2-inch in diameter but will not cut chain moorings. Explosive cutters are of two types. One utilizes a shaped charge to cut the mine mooring; with the other type an explosive charge propels a cutting chisel. Some explosive cutters are capable of severing chain moorings up to 1-1/8 inches in diameter.

SWEEPING MAGNETIC MINES.— As defense against magnetic mines, minesweepers are constructed of wood and stainless steel, aluminum, and other nonmagnetic metals which, along with an elaborate degaussing system, gives them a low magnetic signature. A shallow draft also greatly reduces the danger to the minesweeper of moored or pressure mines.

To sweep magnetic mines, the minesweeper streams a buoyant cable (tail), many yards astern or to the side of the ship, through which a powerful direct current is pulsed, at intervals. This sets up a large magnetic field around the cable and influences the mines.

SWEEPING ACOUSTIC MINES.—Sweeping acoustic mines is similar to magnetic minesweeping in that the effect of an approaching ship must be produced artificially. This is done by towing a noise maker, of which there are numerous types, astern of the sweeper. In one commonly used type, a direct current motor actuates a striker that strikes a diaphragm to produce sound wave. Current to the motor may be pulsed or modulated to give the effect of an approaching ship. The approaching effect is vital because a sudden sharp noise, such as an explosion, will not fire an acoustic mine; it merely actuates a countermine bypass circuit designed to prevent a mine from being fired by the explosion of an adjacent mine or depth charge.

SWEEPING PRESSURE MINES.—For many years the Navy unsuccessfully attempted to artificially produce the effect of a ship passing over pressure mines in an effort to detonate them. The Navy therefore decided to use a ship itself. The first operational MMS (minesweeper, special), delivered in 1969, sweeps pressure mines as well as acoustic and magnetic types. For protection against pressure-mine detonations, the hull of the Liberty-ship conversion has been strengthened, underwater apertures closed, and hold spaces filled with formed flotation material and water ballast. The bridge is shock-mounted.

CHAPTER 13

ANTISUBMARINE WARFARE

In the words of NWP 24, Antisubmarine Operation, "the basic mission of antisubmarine warfare is to deny the enemy the effective use of his submarines." This is a broad mission and includes not only antisubmarine warfare (ASW) operations but also operations against their supporting forces, operating bases, and construction facilities.

ASW can be considered as having offensive and protective phases. Offensive tasks associated with ASW include destruction of enemy submarine bases, repair facilities, and construction facilities; the prevention of enemy submarine movement from place to place; the destruction of submarines enroute to and from their operating areas; and the destruction of enemy submarines in their operating areas. (The distinction between these last two is important operationally.) Protective tasks associated with ASW include establishment of operating methods which will ensure safe arrival of shipping at destination, and protection of ships and shore installations against submarine attack.

Operations utilized to accomplish the offensive tasks include strike operations and hunter-killer (HUK) operations. Protective operations include naval control of shipping, escort operations, screen operations, support operations, and harbor and area operations. Operations that may be protective, offensive, or both include mining, search, and patrol operations. Note that offensive operations may be protective in purpose; there is no need to make too sharp a line of demarcation between offensive and protective.

The classical concept of the Navy's wartime mission, as expressed early in this text is to maintain control of the seas so that we can use them and at the same time deny their use to the enemy. A recent corollary to this concept adds a new method of attack to the Navy's arsenal—the guided missile launched against major enemy land targets by naval vessels hundreds or thousands of miles distant—and simultaneously lays on the Navy the chief burden of defending U.S. territories against just such an attack by the enemy.

The submarine has roles to play both in the classical concept of the Navy's mission and in these newer corollaries. An enemy may be capable of pitting against us submarines as advanced as our own, and as well (or even better) adapted to launching guided missiles with nuclear warheads against our own cities. Such activities as the prodigious and continuing production of Soviet submarines show that the military planners of foreign countries are by no means incapable of making similar strategic estimates—and acting upon them.

Against this threat, unprecedented in the history of warfare, it is the Navy's primary responsibility to maintain constant vigilance, and to be continuously prepared to prevent and counter every attack. It is no longer enough to prevent submarine attacks on our own or Allied shipping and naval vessels, important though this is. It has become necessary to protect against missile-carrying submarines wherever they may be. This new dimension added to the concepts of ASW sets up a new requirement. The need is to find and keep under surveillance all enemy submarines before they can reach a spot within missile launching range of our coasts.

Most of what has even now been developed by way of doctrine techniques and equipment cannot be completely revealed in this textbook for security reasons. But the student should realize that a massive effort by the Navy and other agencies, both in and out of the Armed Forces, is under way to solve the problems implied by this threat, and he should realize too that when he is on active duty the chances are very good that he will be called upon to participate in this effort.

Let us now consider briefly the submarine threat as it has been in the past and as it may be in the future. In this article and in the remainder of this chapter we are primarily concerned with how the submarine can be detected,

located, and attacked by surface forces with the aid of friendly air and subsurface forces. The strategic role of the submarine as a guided-missile platform is beyond the scope of this chapter.

In this chapter we are concerned primarily with ASW weapons and associated fire control and detection systems, rather than with operations as such, but operations will be discussed to the limited extent necessary to explain the use of ASW equipment.

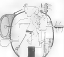
HISTORICAL DEVELOPMENT

The first successful submarine was built in 1620 by Cornelius Van Drebel, a Dutch physician. During repeated trials in the Thames River, he maneuvered his craft successfully at depths of 12 to 15 feet.

Various other European designers of that time constructed submersible craft also. But they failed to arouse the interest of any navy in an age when all concepts of the potentialities of submarine warfare still were far in the future. Most of the early craft were of wooden frames, covered with greased leather or similar material, and propelled by oars. Different methods of submerging were thought of and some were tried. One inventor's design consisted of a number of goatskin bags built into the hull, each connected to an aperture in the bottom. He planned to submerge the craft by filling the skins with water, and to surface it by forcing the water out of the skins with a "twisting rod." Although his vessel was never built, it seems that this was the first approach to the modern ballast tank. Another inventor actually submerged his craft by reducing its volume as a result of contracting the sides through the use of hand vises.

Ideas were plentiful, some fanciful and grotesque, but some contained elements capable of practical application. Lack of full understanding of the physical and mechanical principles involved, coupled with the almost universal conviction that underwater navigation was impossible and of no practical value, postponed the attempt to utilize a submarine in naval warfare during the early period.

A submarine was first used during the American Revolution as an offensive weapon in naval warfare. The Turtle (fig. 13-1), a one-man submersible designed by David Bushnell and hand-operated by a screw propeller, attempted to sink a British man-of-war in New York Harbor.



110.104
Figure 13-1.—The Turtle of David Bushnell from a drawing by Lt F.M. Barber, USN, 1875.

The plan was to attach a charge of gunpowder to the ship's bottom with screws and explode it with a time fuze. After repeated failures to force the screws through the copper sheathing of the hull of HMS Eagle, the submarine gave up, released the charge, and withdrew. The powder exploded without result, except that the Eagle at once decided to shift to a berth further out to sea. Although the attack was unsuccessful, the "idea" for a submarine was there, and it grew until the submarine eventually became a potent weapon for attacking ships.

On 17 February 1864 a Confederate hand-propelled submersible carrying a crew of six men sank a Federal corvette that was blockading Charleston Harbor. The Confederate submarine Hunley used a spar torpedo attached to her bow to ram and sink the Union Frigate Housatonic. This is the first recorded instance of a submarine sinking a warship.

The submarine first became a major component in naval warfare during World War I, when Germany demonstrated its full potentialities. The heavy losses inflicted by German U-boats on allied shipping almost swung the tide of the war in favor of the Central powers. Then, as now, the submarine's greatest advantage was that it could operate beneath the ocean surface where detection was difficult. Sinking a submarine was comparatively easy, once it was

found—but finding it before it could attack was another matter.

During the closing months of World War I, the Allied Submarine Devices Investigation Committee, termed ASDIC, was formed to obtain, from science and technology, more effective underwater detection equipment. The committee developed a reasonably accurate device for locating a submerged submarine. This device, a trainable hydrophone, was attached to the bottom of the ASW ship and used to detect screw noises and other sounds that might come from a submarine. Although the committee disbanded after World War I, the British made improvements on the locating device, during the interval between World War I and World War II, and named it ASDIC after the committee.

American scientists further improved on the device, calling it sonar, an acronym for sound navigation, and ranging.

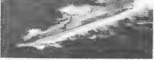
In World War II, submarines sent millions of tons of shipping to the bottom. In what since has come to be known as the Battle of the Atlantic, the U.S. Navy and her Allies teamed together to hunt down undersea raiders, thus gaining one of the important victories of the war.

At the end of World War II, the United States improved the snorkel (a device for bringing air to the crew and engines when operating submerged on diesels) and developed the Guppy submarine. The Guppy (short for greater underwater propulsion power) is a conversion of the fleet-type submarine of World War II fame. A Guppy submarine is shown in figure 13-2. The only change in outward appearance is the superstructure. It was changed by reducing the surface area, streamlining every protruding object, and enclosing the periscope shears in a streamlined metal fairing. Performance increased greatly with improved electronic equipment, additional battery capacity, and the addition of the snorkel.

The world's pioneer nuclear-powered submarine is the USS Nautilus, SSN 571 (fig. 13-3). The Nautilus, commissioned in September 1954, is 320 feet in length and has a standard surface displacement of 3,180 tons. The Nautilus introduced the bulbous bow for better underwater performance. She refueled for the first time in 1957. Like all nuclear submarines she is designed to travel faster under the water than on the surface.

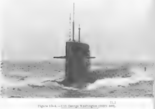
An intensive building program for nuclear ballistic missile submarines has resulted in the addition of many such ships to the operational fleet. The prototype is USS George Washington, SSBN 598, (fig. 13-4).

USS Skipjack, SSN 585 (fig. 13-5) is the first nuclear submarine whose hull is a radical departure from the conventional idea of submarine hulls. Diving planes on the sail result in increased maneuverability.



71.1-346
Figure 13-2.—Guppy submarine.

71.1
Figure 13-3. — USS Nautilus (SSN 571).



71.1
Figure 13-4. — USS George Washington (SSBN 598).

71.1
Figure 13-5. — USS Skipjack (SSN 585).

THE SOVIET MENACE

Soviet submarines can in many respects be compared to American types. The Soviet submarine fleet consists of over 400 submarines, most of which are modern, long range units constructed during a massive postwar building program. This program increased steadily after 1950 and reached a peak construction rate of nearly 100 submarines in 1956, after which there was a marked slowdown in submarine construction. It is probable that the Soviets had reached their desired numerical goal and shifted emphasis to improving the quality and strategic capabilities of the submarine force.

The total threat posed by the Soviet submarine force is increasing steadily. This is because the older submarines being phased out have a marginal capability under conditions of modern warfare. The new submarines, which include a growing number capable of launching ballistic missiles, as well as new conventional attack types, are a vastly more dangerous threat. The Soviets now have in operation a number of nuclear submarines. Thus it is reasonable to suppose and realistic to anticipate that ASW forces opposing them will find the Soviet submarine and its weapons far from backward technologically.

SUBMARINES: ADVANTAGES AND DISADVANTAGES

As seen by ASW forces on the surface, the submarine has the following advantages:

1. Concealment. The submarine is concealed when submerged and is hard to detect because of its low silhouette even when surfaced. A snorkeling submarine or a submarine at periscope depth is visible to a surface or airborne observer, and shows up on radar, but if the sea surface is at all agitated such detection quickly becomes marginal or impossible. Except in certain unusually transparent ocean areas (in localities of the Pacific and Caribbean, for example) a completely submerged submarine is totally invisible to the surface or airborne observer armed only with optical aids and radar. It can be detected by sonar, but this method

has severe limitations, as will be brought out later.

2. More highly trained and developed personnel, both physically and professionally. In virtually all the navies in the world submarine personnel are selected for their superior potential and proficiency, and receive more training in submarine operations than the average naval officer or enlisted man receives in ASW.

3. Passive detection capabilities. Because submarines are so hard to detect, ASW forces must search actively for them, and in the two chief methods of searching, they reveal themselves to the submarines in searching. A radar pulse from a searching ASW vessel can be detected by a sensitive ECM receiver at a much greater range than that at which a submarine's silhouette (or its even less obtrusive antenna, periscope, and snorkel) will return a definite echo. This is particularly true when weather is poor or the sea surface is agitated. A sonar pulse similarly can be heard by a submarine much beyond the maximum range at which the sonar will produce a reliable echo. Lastly, although a submarine snorkeling or on the surface can be seen by surface or airborne observers, usually an observer in the low-lying submarine will see the observer first.

4. Immunity to surface water. A submerged submarine avoids the buffeting of rough surface winds and waves.

5. Reduced noise production. Other things (such as type of listening gear, screw rpm, speed through the water, etc.) being equal, a submarine listening at moderate depth will probably hear a surface vessel before the surface vessel can hear the submarine. At present, the main reason for this is cavitation produced by rotation of the ship's screws in the water. (This phenomenon is explained in the next chapter.) As water pressure increases, cavitation and the noise it produces decrease. A submerged submarine is under greater pressure because of its depth, hence it produces less cavitation noise. It is also true that an electric drive inherently is likely to be somewhat quieter than a steam turbine or Diesel plant, and that conventional submarines generally run at lower speeds submerged than they do on the surface, so that they tend to be quieter even without taking cavitation into account. Recent hydrodynamic investigation indicates that the bow wave (the "bone in a ship's teeth") produced by hull movement on the surface is inherently more wasteful of power, hence noisier, than movement of water around a Skipjack type hull structure completely submerged in the water. Nuclear-powered boats, which have steam-driven turbines, do create more underwater noise than the electrically driven conventional submarines. Speed and depth capabilities partially compensate for this, however. It seems relatively safe to predict, therefore, that the noise-detection advantage that submerged submarines now have is likely to continue in the future.

6. Speed. With the advent of Nuclear-powered submarines and Skipjack type streamlining, ASW craft no longer hold a speed advantage over the submarine.

Not all the advantages are with the submarine. In the following respects the ASW forces have the advantage:

1. Variety of weapons. Submarines can be attacked with a number of weapons, such as mines, torpedoes, and missiles. Submarines at present have only torpedoes and the recently developed submarine rocket in their antisurface arsenal. Fleet ballistic missiles (Polaris/Poseidon) are not intended for use against surface forces.

2. Vulnerability. Even relatively slight damage to a submarine can force it to surface—relative, that is, to the damage required before a surface ship is put out of action. Slight damage that does not force it to surface may increase its noise output (for example, it may be necessary to start pumps because of a leak) and give its position away to listening observers.

3. Personnel endurance. This is limited by the physical conditions of life aboard a submerged submarine, particularly of the less advanced types, and the combined psychological and physical strains to submarine personnel under attack, even when the attack is not lethal.

4. Number. ASW forces are generally concentrated so that more than one ship plus aircraft attack a submarine. In theory, two or more submarines can work together in an attack, but any attempt at communication between the submarines will give away their position, destroying the submarines' main advantage. Moreover, whereas communication between ASW forces is relatively easy (by radio, flashing light, etc.) and cannot be detected by submerged submarines, communication between submarines is at best likely to be garbled and difficult, as well as tactically disadvantageous.

SUBMARINES AND ANTISUBMARINE WARFARE IN THE FUTURE

No man can say just what warfare will be like in the future, but the outlines that can be conjectured are clear enough to show that naval forces under the sea surface will have much to do with determining who has command of the sea. Based on past experience and on new developments, submarines will likely be used in any or all of the following ways by both sides:

1. To destroy the enemy's navy and merchant marine.
2. To impede or cut off the flow of supplies and troops by threat of attack on merchant shipping.
3. To deny use of shipping lanes and harbor areas to the enemy's merchant shipping and naval units by submarine-planted mines.
4. By causing the enemy to concentrate on antisubmarine warfare, to divert him in greater or less degree from his primary mission of winning the conflict.
5. To mount direct attacks by submarine-launched guided missiles and rockets.
6. To function as pickets.
7. To function as transports in situations where the submarine's special characteristics are important.
8. To function as antisubmarine units.

Though in many respects antisubmarine warfare of the future will resemble that of World War II, there will be great differences. The advent of nuclear-powered ships and submarines, and nuclear weapons creates a growing challenge in the antisubmarine warfare problem of our modern Navy. Detection equipment and tactics are constantly undergoing revision and improvement in order to keep abreast of this changing technology.

Our present ASW ships, such as the destroyer, are formidable adversaries against any submarine. The destroyer can remain at sea for extended periods of time. It carries the latest sonar, electronic countermeasures (ECM), and communication equipment, plus the weapons to go with them and the facilities for reloading under long-endurance wartime conditions. Not only can the destroyer defend itself against enemy attack, but it also can screen and protect other units.

SONAR AND OTHER UNDERWATER TARGET LOCATION SYSTEMS

Now that we have surveyed the outlines of the problem and in general terms compared the capabilities of the adversaries, submerged versus surface and airborne, we are ready to investigate (still in general terms) how, from the point of view of surface ASW forces, the underwater target can be located and attacked.

We have elsewhere in this book discussed methods of locating and attacking surface targets. When surfaced, the submarine is a surface target, and it is not necessary to discuss further how a surfaced submarine is attacked.

To attack a submerged submarine, it is first necessary to detect it, establish its location and its rate of movement in bearing and depth, and then solve the fire control problem to predict its future location so that an ASW weapon can attack it. When more than one weapon is used, the problem must be solved for each.

The blind time (time elapsed between firing and predicted impact of missile) of ASW weapons is much greater than that for gun and rocket fire control. Therefore, ASW weapons are designed to be effective over a larger area than, say, gunfire at the same range.

The chief method of detection and location of submerged submarines by surface craft is by using sound, which travels underwater about four times faster than it does in air. The primary method of sound detection, sonar, will be treated presently. Magnetic methods can be used by aircraft, but at present, they are not adaptable for use in surface vessels. Other methods that may be under development cannot be discussed in this book.

Although at present underwater target detection and location by surface craft is done by one method (sonar) to the virtual exclusion of others, a variety of weapons can be used to attack the target. Some of these weapons are discussed later in this chapter (to the extent that security classification makes possible).

Echo-ranging equipment, commonly referred to as sonar, is installed on board ships to determine ranges and bearings on submerged submarines by means of sound waves. To a lesser extent, it is used for navigation purposes. In pilot waters, especially in low visibility, it may be used to locate reefs, other submerged objects, and buoys.

When sound waves impinge on any submerged or partially submerged object, some of their energy is reflected in the manner of an ordinary echo. In active sonar, a sound pulse is projected and, in turn, the echo is received by means of a transducer which is usually located in the water forward and on the keel of the ASW vessel (fig. 13-6). The signal-receiving and indicating equipment (the so-called stack or sonar control indicator) is located in a space known as sonar control. The signal-transmitting equipment, requiring no operator, is generally installed in a space immediately above the transducer.

The principal sonars in use during World War II projected a narrow beam of sound into the water, and target indications were returned as audio responses from a speaker or headset. A thorough search was a slow process in which the operator hand-trained the transducer in increments of 2-1/2° to 5°, according to search doctrine in force. (This was the "search light" type sonar.)

At the close of World War II, the Navy perfected a new type of search sonar known as scanning or azimuth search sonar. With each outgoing burst of sound, scanning sonar transmits the sound pulse in all directions simultaneously and picks up echoes from any or all points. In addition, scanning sonar offers both video and audio presentation of target information.

The performance of sound waves when transmitted through sea water is a complex study in itself. However, a knowledge of certain features of this subdivision of physics is important in understanding how sonar is used. These are:

1. Speed of sound variations. Temperature and, to a much lesser extent, pressure and salinity differences cause variations in water density which, in turn, cause variations in the speed of sound in sea water. This results in varying values of sonar range which must be taken into account since sound-ranging sonar, like radar, measures range by the time interval between transmitting a pulse and receiving an echo. In addition, variations in sound transmission speed cause the sound beam to be refracted or bent as it passes through the water. This is discussed separately below. The speed of sound in sea water at temperature 32°F, and at normal conditions of salinity and atmospheric pressure is approximately 4800 feet per second. Any increase in pressure or salinity will result in

53.117
Figure 13-6.—Elements of sonar system.

only slight increases in the speed of sound. Any increase in temperature however, will result in an appreciable increase in the speed of sound.

2. Sound beam refraction. As mentioned above, the variations in speed of sound caused by temperature produce refraction of the sound beam. This refraction, unless corrected for, can result in serious errors in the measurement of sonar range, and a reduction in detection range.

3. Attenuation. Sound waves propagated through sea water are attenuated rapidly; hence the range at which detection is possible by sonar is reduced.

4. Echoes. Echoes, both single and multiple (reverberations), are received from marine life, the sea bottom, surface disturbances, and various irregularities in the fluid medium, as well as from submarines.

Although adverse water conditions may limit range and make bearing definition difficult, ASW personnel are trained to get optimum results from their equipment under all conditions. They are trained to predict sound behavior and to apply the results reliably to the antisubmarine problem. Sonarmen quickly classify a contact by its appearance on the cathode ray scope, the quality of the sound, the bearing spread, its relative motion, etc. Sonar research has established certain sound "patterns," based principally on underwater temperatures. With the aid of the bathythermograph (BT), a device for measuring water temperatures down to 900 feet, it is possible to predict the sound pattern and to introduce these data into the sonar system.

SONAR PRINCIPLES

There are two principal modes of sonar operation. Passive sonar listens only; the sounds it detects are those originating with the target. Active or echo-ranging sonar radiates a powerful brief pulse of sound vibration into the water, then listens for the echo. The term "sonar" without qualification denotes active sonar. Any underwater object that returns an identifiable sonar echo or produces a discrete sound is a sonar contact.

As in radar, the listening device can indicate the bearing of the signal source it hears. In active sonar the returning echo is timed and the equipment can indicate the range to the target. The equipment can display a video presentation much like a PPI-scope, and also produces an audible output.

The video presentation of the echo permits quick, accurate determination of target range and bearing; a Sonarman's trained ear can analyze the audio reproduction of the echo and determine (a) the nature of its source and (b) its movement with respect to own ship. Analysis to determine the nature of the echo or sound source (this aspect of auditory analysis of sonar sounds applies to both echoes and original noises) is based on experience with sounds produced under varying conditions by different kinds of sea creatures as well as different kinds of targets and simulated targets. (A submarine may for example release a quantity of air from a torpedo tube; the air bubbles will return an echo and show up on the sonar video presentation.) In addition, echoes from moving targets have doppler. Doppler is a change in frequency of the echo (as compared with the frequency of the original sonar pulse) from a moving target having motion along the line of sound. (Anyone who has heard the change in pitch of a railway locomotive whistle or horn as a fast-moving train passes a stationary listener has heard a rather obvious example of the Doppler effect, which was named after Christian Johann Doppler, a 19th-century Austrian physicist.) Doppler indicates relative target motion.

In sonar, doppler is a rather subtle effect and its consistent detection and evaluation require an ear highly sensitive to audible pitch changes, plus much training and experience with audibly reproduced sonar echoes. Sonar systems produce sound pulses of very high and often ultrasonic frequency (i.e., frequencies beyond those of normal human hearing). To produce sonar echoes at audible frequencies in the range (in the neighborhood of 800 hertz) to which the human ear is most sensitive and can best discriminate pitch changes, sonar systems use beat frequency oscillators to change the frequency of the received echoes to about 800 hertz.

Equipment designed to function as active sonar can be used passively if desired. Listening devices designed for passive operation only are called hydrophones. (These are normally installed only on submarines.) Underwater telephones (colloquially called "Gertrude") used for voice communication, also work on sound conduction principles, but are not to be confused with sonar.

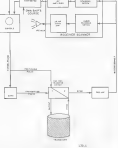
Sonar is the primary means of detecting a completely submerged submarine, and, in general, it is the only means a surface vessel has of detecting an underwater target. Echo-ranging (scanning) sonar is the most effective for shipboard use.

REPRESENTATIVE SCANNING SONAR

A representative scanning sonar (fig. 13-7) includes a console, transmitter, transmitter-receiver transfer switch, transducer, receiver, various amplifier units and switches, and a data converter.

A feature of all modern sonars is that echoes are displayed visibly as well as audibly. The visible display is made by a cathode ray tube (CRT). In some equipment, two CRTs may be operated in two different modes, ship center display (SCD) and target center display (TCD). In SCD mode, own ship is represented by the center of the CRT, and echoes from the target and other underwater objects appear as bright spots about it. In the TCD mode, if the cursor is on target, the bright spot representing the target appears at the center of the display. Depending on range and range scale, own ship may not even appear. The ship center display mode is used in searching; the target center display mode is normally utilized for tracking.

For audio presentation, a returning echo, after conversion to an electrical signal and amplification, is changed to an audible frequency and sent to a headset or loudspeaker near the control indicator, where it is heard as a "ping." The ping is of value in target identification and in the determination of doppler.



130.6
Figure 13-7.—Typical scanning sonar.

The console or sonar indicator control, commonly called the stack, is the heart of the installation. All necessary operating controls are mounted on its face, and near the center is the CRT.

A principal function of the console is to initiate the keying pulse, which is sent to the transmitter. When the transmitter is thus keyed by the console, it generates a power pulse to the transmit-receive transfer switch.

The transfer switch acts like a gate that, in one position, permits transmission and blocks reception; in the other (normal) position, the equipment can only listen for (receive) an echo.

Transducer

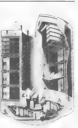
By means of 48 staves (segments of a transducer, similar to electromagnets), the transducer (fig. 13-8) converts the electrically energized signal to mechanical energy and sends it out in the form of a sound pulse. During the silent period between pulses it also acts as the receiver, listening for echoes.

Pulsing may be omnidirectional, meaning that the pulse is sent out in all directions at once, or it may be rotating directional. In rotating directional transmission, several staves are excited simultaneously to produce a sound beam. Several more adjacent staves are excited and produce the next beam. The effect is rather like a series of spotlights mounted in a circle being flashed on and off in turn. The beaming is done so rapidly, however, that the entire 360° arc is covered almost instantaneously. Total energy is applied to the several staves and, thus, is concentrated in each pulse rather than being dispersed in all directions at once. Targets, therefore, can be detected at much greater ranges.

After every pulse, each stave (fig. 13-9) reconverts mechanical energy induced by return echoes to electrical energy and sends a signal to its own amplifier in the preamplifier unit. Because signals from staves that have picked up echoes vary, a reception pattern is determined. This pattern is maintained until presented on the scope.

Some transducers function on the principle of magnetostriction although most now are ceramic type. When certain metals (nickel, in this case) are in a magnetic field, they will change in length slightly, depending on the direction and intensity of the magnetic field. If the magnetic field changes in direction periodically at a given frequency, the metal will change in length in synchronism with that frequency. This is the magnetostrictive effect. This mechanical vibration can be transmitted to the surrounding medium—for example, water. The effect is reversible; that is, vibration picked up from the surrounding medium causes the metal to vibrate similarly, and the resulting change in the magnetic field will induce a voltage in a coil surrounding the metal piece. For transmission of a sound pulse, the coil can be excited by an alternating current of suitable frequency; for reception, the coil can be connected to an amplifier which will amplify voltages induced in it.

Ceramic-type transducers are the most common ones now being built, because of their high



71.48
Figure 13-8.—Scanning magnetostrictive transducer.

sensitivity, high stability, and relatively low cost—plus mechanical properties that allow construction of almost any reasonable shape of size.

Scanning Switches

Scanning switches are the components that give scanning sonar its name. Scanning sonar's goal is to display a full azimuth presentation that, possessing sensitive directivity, provides an accurate target bearing. The means used to achieve the goal are two scanning switch assemblies, an audio and a video.

The two scanning switches have much in common, being roughly comparable to a synchro-mechanism with a rotor revolving within a stator.

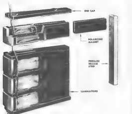


Figure 13-9.—Exploded view of one scanning sonar transducer stave.

The 48 separate signals enter the stator and generate voltages corresponding to the echo received by each stave and at its exact bearing. When the rotor is matched to any bearing, the signal generated in the corresponding stave passes through the rotor to an amplifier and then either to the audio or video display. Thus, we achieve directional presentation; the scanning switch relays a signal only when trained on the bearing of the returning echo.

AUDIO SCANNING SWITCH ASSEMBLY.—In the audio switch assembly the switch rotor may be trained as desired by the operator. It relays echoes from any 120° arc of the transducer. This arc (or audio channel) is centered on the bearing selected by the operator's manual control. Signals originating within the bounds of the audio channel are relayed to an audiofrequency/radio-frequency (AF/RF) amplifier.

The AF/RF amplifier increases the strength of the signal so that it yields an audible echo when changed from electric to acoustic energy.

VIDEO SCANNING SWITCH ASSEMBLY.—The video scanning switch rotor is not selective in train, but revolves rapidly at a constant speed (often as much as 3600 rpm). When matched to the bearing of the echo, the video scanning switch relays the electrical current induced in

the staves to an RF amplifier. The video rotor, having a much narrower response arc than the audio rotor, accepts signals received by only one stave at any given instant. It actually scans more than one stave at a time, but lag-line phasing admits the signal from only one stave at any time.

The RF amplifier amplifies the signal so that it can effect electronic printing on the face of the CRT.

Because the scanning switch and the electronic sweep generator are driven by a common constant-speed motor, their rotation is synchronized. Thus, the indications presented on the CRT are realistic representations of returning echoes. Echo pips are printed at the proper bearing because both the sweep and the rotor are matched at the same bearing when the echo is allowed to enter the system. Echo pips are printed at the proper range because the electronic sweep is moved outward from the center of the scope at a rate proportional to the speed of sound in the surrounding water.

The resultant of the actions of the scanning switch and the sweep generator is the presentation on the face of the cathode ray tube. The sweep originates in the center, indicating initially the reverberations at the transducer face. It then continuously expands in a spiral manner until it reaches the outer edge of the CRT (or the end of the range cursor, if some intermediate range setting is used).

Signal Data Converter

The signal data converter affects the last stage of the reception cycle preceding the actual display of target information. It receives own ship course from the gyro compass, converts this information to usable form, and transmits it to the console where it orients the sweep display on the CRT.

Video Presentation

As stated previously, the video presentation on the CRT may be either ship center display (SCD) or target center display (TCD).

SCD MODE.—Figure 13-10 shows the main features of a typical SCD sonar CRT display. This is a highly conventionalized diagram, and it is not intended to show features realistically.

In the SCD mode, a line (cursor) originating at the center of the CRT and parallel to the

110.105
Figure 13-10.—Typical SCD sonar CRT display.

bearing of the audio scanner, is the first presentation. With this the operator can read on a dial around the CRT's face the bearing of echoes he hears.

Immediately following the printing of the cursor on the CRT, the pulse is transmitted. The electron beam appears and begins the expanding sweep at a rate proportional to the time it takes the transmitted pulse to travel. This expanding sweep is spiral. The electron beam prints as it revolves in synchronization with the rotating video transducer scanner. The angular position of the beam corresponds with the instantaneous position of the video transducer scanner. Presence of an echo produces a bright spot on the face of the CRT, at a point corresponding to the range and bearing of the object reflecting the pulse.

As the pulse is transmitted, a broken line, originating at the pulse presentation, and bearing 180° from own ship's heading, is displayed. This is known as the stern line, and it assists the operator in determining areas for searching.

Since the equipment is alert in all directions because of the rapid scanning feature, a true geographic plot is produced of the area surrounding the ship. Noise sources other than echoes from the transmitted pulse are received also, and are presented as bright spokes or wedges on the CRT at their correct bearing. The operator

can determine range and bearing to a contact by training the cursor to the center of the spot and adjusting its length. The bearing may be read directly from a dial. Cursor length may be varied by a control on the control indicator. Cursor length is proportional to the range and, when the end of the cursor is superimposed on the target echo, range may be read from a dial on the control indicator.

When searching for a target, the sonar system is set so that the two video signals (left and right) from the scanner are added or summed. This provides a broad, easily seen pip for an echo. When the target pip has been identified and the sonar system is set to track it, the system is switched for difference operation. The left- and right-scanner outputs are then subtracted, and the target pip becomes small and sharp so that it can be tracked most effectively.

The video presentation is normally oriented and stabilized. The top of the CRT represents north. Own ship course is received from the ship's gyrocompass. Bearings to echoes are true. Without gyro input, the presentation is in relative bearing, with ship's head at the top of the CRT at 000°. Changes in own ship course will, when the presentation is in relative bearing, cause the entire CRT picture to rotate. When the presentation is in true bearing, the electron beam in the CRT is electrically rotated to keep the pattern it prints oriented.

The video presentation is also compensated to eliminate the effect of own ship roll and pitch, and keep the CRT picture stabilized. Reverberation or minor sound reflections from such sources as surface waves, small fish and other sea life, etc., shows up as small spots or light patterns. Noise sources, as distinguished from echoes (either random or from specific targets), show up on the CRT as radial spokes or wedges rather than pips. Sonars are responsive to a wide range of frequencies; unlike radar, a sonar is not tuned to receive a specific frequency. It therefore picks up all kinds of noise sources. This is called hydrophone effect, and it occurs during active mode operation, as well as in passive or listening mode. Since the CRT indications of noise sources do not arise from timed echoes of the transmitted pulse, there is no blip that shows range to the noise source. The spoke shows only bearing. The spoke can be made broad or sharp by sum or difference reception.

TCD MODE.—In the target center display the contact, instead of own ship, is displayed in the center of the CRT. The expanding spiral sweep presentation is used, but the origin of the sweep (own ship position) is moved to a position off the face of the CRT, and the contact is positioned at the center of the scope.

Only a circular portion of the entire sweep is displayed on the CRT when the contact is in the center, unless range to the contact is within the display limitations of the scope. In that case, both own ship and contact would be presented. When the contact is in the center of the scope, dials on the control indicator show the range and bearing to the contact from own ship.

The stern line remains with the transmitted pulse for both types of display. It is visible when the equipment is in target center display only when own ship's transmitted pulse comes into display range on the CRT. Most display conditions remain the same for both types of display.

Audio Presentation

As stated earlier in this chapter, the returning echo, after conversion to an electrical signal and amplification, is changed to an audible frequency and sent to a headset or loudspeaker near the control indicator, where it is heard as a "ping." This ping is of value in target identification and in the determination of doppler.

The outgoing (transmitted) pulse from the sonar is, so far as possible, suppressed so that it does not show on the CRT or become audible on the sonar's sound reproducers. To determine whether the pitch or frequency of the echo has been changed by the doppler effect, the sonar operator compares the echo aurally not with the original pulse but with the reverberation return, since the average reverberation source is moving at zero speed. (The sonar circuitry electronically compensates for doppler effect in reverberation caused by own ship speed; therefore, doppler depends upon only relative target motion toward or away from own ship.) Since acuity of pitch discrimination varies with frequency, a frequency is selected in the region where human ears are most sensitive to pitch changes—around 800 cycles per second (equivalent to a note in the upper range of the piano keyboard).

Up doppler is the increase in frequency of returning sound waves caused by a target's motion toward own ship. Down doppler is the

decrease in frequency of returning sound waves caused by a target's motion away from own ship. A target which causes up doppler is said to have bow aspect, while a target causing down doppler has a stern aspect. A beam-aspect target has no doppler.

SPECIFIC SONAR SETS

Several different modifications of sonar sets are in use in the fleet today. Two of the latest are the AN/SQS-23 and the AN/SQS-26.

The AN/SQS-23 sonar provides accurate range and bearing information for the fire control system, with ranges greater than those obtained in older systems. The low transmission frequency of the equipment, combined with the rotating, directional transmission and the ability of the transducer to operate at a tremendous power output level, produces a high source level for long range target detection.

The AN/SQS-26 sonar is a long-range, advanced search sonar that represents a radically improved approach in concept and application to present day problems of submarine detection. It is designed to detect all submarines, regardless of their depth and speed and the water conditions.

VARIABLE DEPTH SONAR (VDS)

Without going into the technicalities of the phenomenon, oceanographic conditions frequently are such that there are layers of water with widely varying temperatures. Where these layers meet (layer depth), much of a transmitted sound beam is either reflected or sharply bent (refracted). Submarines operating beneath the layer depth may escape detection because the sound does not reach them or because the returning echo is greatly weakened or mushy. The VDS overcomes this disadvantage because it can be lowered beneath the layer depth, thus improving detection capabilities previously limited by the fixed, hull-mounted sonar.

Older VDS sets consists of a towed transducer operating in conjunction with a shipboard-installed, hull-mounted sonar set. The union is accomplished by providing a transducer within a hydrodynamic towed vehicle, plus a crane-type hoist for lowering, towing, and raising the vehicle (fig. 13-11). The towed transducer is connected electrically to the ship through a cable extending through the center of the tow cable. A switching mechanism in the sonar set permits use of either the hull-mounted transducer or the towed-transducer, or both simultaneously.

51.53
Figure 13-11.—VDS suspended with boom facing aft.

A later type of VDS (not shown) is a sonar set complete within itself. Because it can be made to operate independently of other sonar systems, it is known as the independent variable depth sonar (IVDS).

AIRBORNE SUBMARINE-DETECTING SYSTEMS

Aircraft are used for detecting submerged submarines by means of—

1. Sonar,
2. Sonobuoys, and
3. MAD gear.

Sonar

Sonar equipment (called "dipping sonar") can be used by rotary-wing aircraft (helicopters) to detect submerged submarines. Because it isn't practical to drag sonar equipment through the water at the minimum flying speeds of fixed-wing aircraft, only aircraft that can hover or move at low speeds are suited for sonar detection.

Because of the limited weight-carrying and power-producing characteristics of aircraft, high-powered azimuth type sonar is not carried by aircraft. The equipment is of the "searchlight" type which pings on one bearing at a time, must be trained to the required bearing to detect a target, and presents only an audible echo without video presentation. In spite of these limitations, airborne sonar gear is capable of excellent results because it can be transported from one location to another at a much higher speed than that of any surface vessel, and because, although such aircraft as helicopters are noisy, they produce no water-conducted noise. (Most dipping sonar presently used in helicopters is capable of scanning 360° and also of narrowing the search to a selected bearing.)

In a helicopter, the dip or dunking sonar equipment, all except for a ball-shaped transducer housing and the 500-foot cable from which it is suspended, is located in the helicopter fuselage. When the helicopter has reached a location where the presence of a submarine is suspected, it descends to 10 to 20 feet above the water, and the sonar ball is lowered to about 400 feet below the surface. After searching, the helicopter hauls in the cable. After the cable has been retracted, the helicopter can go to another location. When the submarine is detected and located, the helicopter can "vector in" other aircraft and ASW vessels for the attack, or can itself attack if properly armed.

The search procedure can be completed in a few minutes (especially if the search doesn't encompass the full 360° in azimuth) and the helicopter can be up and away. Present types of submarines have no effective countermeasures against helicopters. This search technique is much more difficult in heavy weather, although improvements in this respect are being made continually. Figure 13-12 shows a helicopter with sonar submerged, searching.

Radio Sonobuoys

Radio sonobuoys are small expendable floating hydrophone or sonar units whose output is radio-broadcast by a small transmitter in the sonobuoy. They are generally dropped to the sea surface by fixed-wing aircraft in the area where enemy submarines are expected to be. Usually more than one is dropped at a time, in a circular pattern around the contact area (as determined by other detection data). An experienced operator, by comparing its pitch (for doppler) as received by each sonobuoy, can estimate the present location and direction of movement of the target. After two to four hours, a soluble plug in the sonobuoy dissolves and allows the unit to sink. While afloat, the sonobuoy indicates its position visually (by releasing red dye into the water or by keeping a lamp lit) and by radar.

Figure 13-13 shows diagrammatically how one type of sonobuoy pattern is initiated by an aircraft in response to surface indication of the presence of a submerged submarine (in this case the oil slick from a submarine that has been damaged). The buoys are planted where they will continue to pick up the submarine's sound as it proceeds underwater. A frequent pattern is a circle of buoys about the area (called the datum) in which the submarine contact is expected.

Magnetic Anomaly Detection (MAD) Gear

Any mass of steel as large as a ship's or a submarine's hull will significantly warp or distort the earth's magnetic field in the vicinity.

3.115
Figure 13-12.—Dip sonar in use by helicopter.

110.106
Figure 13-13.—Radio sonobuoys used to locate submerged submarines.

In influence-type exploder devices in mines and torpedoes, this effect is used to detonate the device when it is quite close to the target. The same principle is used for locating a submarine at a greater distance than this, but the magnetic detecting device must be more sensitive and must be moved at a relatively high speed with respect to the target. For this purpose, MAD equipment is used on fixed-wing aircraft flying at relatively low altitudes (fig. 13-14).

SUBMARINE COUNTERMEASURES

Submarines can and do take specific countermeasures against surface ship and aircraft detection and attack. Some of these countermeasures are similar to those taken by surface ships; these won't be repeated here. Others are designed to make the submarine harder to detect on sonar or hydrophones. Still others are intended to deceive or confuse the attackers. In either case, the result (if successful) is to make the attacker lose contact with his target.

110.107

Figure 13-14.—ASW fixed-wing aircraft fitted with MAD gear.

In practice, the effectiveness of the countermeasure in deceiving the attacker, and the ability of the attacker to penetrate the deceptions and maintain contact, depend principally on the tactical ingenuity of each side. Earlier in this chapter you noted the principal advantages and disadvantages of the submarine as compared with the surface attacker. In ASW, each combatant makes the most of his advantages (including psychological ones) and does his best to overcome the other's stratagems. The variations and combinations possible are endless. ASW has been called a "cat-and-mouse" game. This is not entirely accurate, since the "mouse" is as dangerously armed as his opponent, but in two respects the comparison is apt—one successful blow is likely to decide the issue, and, in contrast to open combat between air and surface opponents, patience and watchfulness over a prolonged period are likely to be the decisive factors.

The list below includes the principal types of countermeasures that submarines can now use.

SUBMERGING. This is the primary natural defense of the submarine against detection. There are several degrees of submerging, from running with deck awash, to snorkel depth (running with the snorkel, periscopes, and antennas just above the water surface, but with the entire superstructure submerged), to periscope depth (with only the attack periscope protruding from the surface), the shallow submergence (about 60 to 100 feet), to deep submergence (at a maximum or "test depth" for the submarine). A snorkeling conventional submarine can continue to run on Diesels and charge its battery. Although it presents a reduced target to visual and radar search, its propulsion machinery is at its noisiest. At any speed exceeding a couple of knots the protruding parts develop a wake

that grows proportionally more noticeable with speed, particularly if the water is smooth. And in very cold weather the Diesel exhaust through the snorkel forms a plume of white vapor. When the submarine is slightly deeper, at periscope depth, the periscope by itself is much harder to spot than the snorkel and associated gear, but it and its wake are still detectable, even if marginally, to radar and eye. At shallow depths (down to 100 feet or so) a speeding submarine does cause noticeable turbulence on the surface if the sea is relatively calm, and its hull can sometimes be spotted visually by aircraft. When the submarine is deeply submerged, its presence is rarely betrayed by any evidence on the surface. Where the sea bottom is not deep, a submarine can rest on the bottom next to a wreck, reef, or turbulent area to present virtually no target to echo-ranging sonar.

SILENT RUNNING. To avoid detection by hydrophone, submarines must reduce noise radiation as much as possible. Chief sources of noise are echo-ranging sonar, operation of propulsion machinery (particularly Diesel engines), operation of other machinery such as ventilating gear and pumps, cavitation produced by rotation of screws above certain critical speeds, and screw noises from other causes (such as deformed blades). A submarine commander can order any of several degrees of silent running, ranging from reduction of running speed and shutdown of echo-ranging sonar to complete stoppage of all machinery and even prohibition of the crew's talking above a whisper. Silent running conditions are ordered, of course, only when the submarine is submerged. A submarine snorkling or running on the surface under Diesel power is at least as noisy as any similarly powered surface vessel. Electric drive at the same speed is much less noisy. Nuclear submarines, as previously mentioned, are as noisy or noisier than conventional submarines; however, they are capable of running at much greater depths.

A submarine running silent can still attack by releasing a "swim-out" homing torpedo against a surface attacker. Firing a conventional torpedo is a noisy procedure that requires forcing a large air bubble out of the torpedo tube along with the torpedo. A "swim-out" homing torpedo propels itself out of its tube, runs upward to set depth and begins to search for its target (while the submarine dives), and homes on the surface ship's screw noises.

USE OF THERMOCLINES. A previous section has explained how the path of sound waves in sea water is distorted by differences in water density. Submarines are fitted with recording bathythermograph units which function whenever the ship dives, so that the presence of thermoclines (interface between warmer and colder water layers) is continuously indicated. The submarine can dive under a thermocline and in most cases cause the attacking vessel to lose contact entirely. The new VDS sets, discussed earlier, make it more difficult for the submarine to use a thermocline as a countermeasure.

HIDING BENEATH SURFACE VESSELS. Because a sonar is relatively "deaf" in the area directly below it, a submarine can find concealment directly below its attacker. Or a submarine can hide directly below some other ship, using the surface vessel's screw noises and turbulent wake to mask its own sonar echo. In this position the submarine can use swim-out, homing torpedoes, as described earlier.

FALSE TARGETS. A mass of air bubbles is detected by sonar as a target. Submarines can eject air through their torpedo tubes to create a false target for the benefit of surface sonar. The target doesn't last long, and it betrays its nature to a sharp sonarman because it has no doppler, but it can distract the attacker long enough to cause loss of contact. A German-originated device specifically designed to eject bubbles for this purpose was called the "Pillenwerfer," which is sometimes used to refer to similar devices on our own submarines.

Another type of false target is the beacon. This is a small battery-powered screw-propelled torpedolike device that can swim out of a torpedo tube and continue until its battery runs down. It emits a continuous or intermittent noise simulating a submarine's screw, sonar pings, or other sounds. A number of different sounds can be produced. After ejecting this device, the submarine usually heads downward and in the opposite direction, while the beacon moves at 1 or 2 knots in the direction in which it was projected. A beacon not only distracts passive sonar search, but also can attract ASW homing torpedoes intended for the submarine.

Submarines can also eject quantities of oil and debris to simulate their own destruction, and thus motivate surface attackers to call off the attack.

ASW WEAPONS

Older types of ASW weapons include, in addition to older versions of homing torpedoes, older depth charges and hedgehogs. Because these are obsolescent, they are mentioned only briefly.

A depth charge essentially is merely a container filled with about 300 pounds of high explosive, and designed to explode at a predetermined depth. It is extremely difficult to obtain a direct hit with a depth charge; and, to be fatal, the explosion must occur within about 20 feet of the target.

An improvement over the depth charge is a 7.2 inch diameter mortar-type projectile called the hedgehog. Hedgehogs are mounted in groups of 24 and are fired in pairs; a salvo results in a circular pattern over the apparent position of the submerged target. This weapon has no depth setting and explodes only on contact. Because the charges have a fixed range, the pattern can be launched successfully only when the ship reaches correct firing range.

The Navy's primary operational ASW weapons today are (1) antisubmarine rockets (Asroc), (2) submarine rockets (Subroc), (3) antisubmarine torpedoes (Astor), and (4) conventional torpedoes.

ASROC

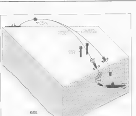
The Asroc (whose launcher is shown in figure 13-15) is a supersonic, shipboard-launched, solid-fuel, rocket-propelled antisubmarine ballistic projectile. The missile has two configurations—one with a depth charge and one with a torpedo.

The goal achieved by Asroc is the destruction of submarines at long ranges. This objective is achieved by delivery of a torpedo or atomic depth charge through the air to a point in the water from which it can either attack under the most favorable circumstances or have the submarine within its lethal radius (fig. 13-16). The payload is a part of an unguided missile which is propelled by a rocket motor and stabilized by an airframe throughout its powered flight. Separation timers jettison the airframe and motor after a preset time. From separation to water entry, different methods of stabilization are employed, depending on the payload. The depth charge descent is stabilized by a fin network during the entire drop. The torpedo also has such a network, but it employs, in addition, parachute stabilization. Besides stabilizing the torpedo descent, the parachute also decelerates it to a safe water entry velocity

15.106
Figure 13-15.—Asroc launcher.

to avoid damaging the highly sensitive electronic components.

Before the missile is launched, the submarine is located by sonar, and the range, bearing, and other pertinent data are transmitted to the fire control system. The fire control system automatically computes the anticipated target position, sets a time-to-separate into the timers on the airframe, and keeps the launcher trained



15.114
Figure 13-16.—Asroc.

on the desired water entry point, so that the missile can be fired at will by simply closing the firing circuit.

SUBROC

The Subroc (the acronym for submarine-launched rocket) is an antisubmarine weapon with a nuclear warhead. It is launched from a submarine torpedo tube by conventional methods. As shown in figure 13-17, after clearing the submarine, a rocket motor ignites and propels the weapon upward and out of the water. An inertial guidance system then directs Subroc toward its target. At a predetermined range, the motor and depth bomb separate, the latter continuing toward the target area. Upon reentry into the water, the bomb sinks to a preset depth and the warhead explodes.

Although Subroc is designed primarily as an antisubmarine projectile, the target may be either a submarine or surface ship. The Subroc system can fire missiles in rapid succession, an important defense against enemy wolfpack tactics. In essence, Subroc may be considered a submarine-launched Asroc.

ASTOR

The antisubmarine torpedo (Astor) is an underwater-to-underwater or surface, wire-guided, electrically powered, high-speed torpedo

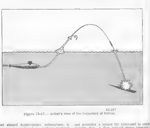

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Figure 13-17.—Artist's view of the trajectory of Subroc.

deployed aboard hunter-killer submarines. It can carry a conventional or nuclear warhead and can be used against surface or underwater craft.

REPRESENTATIVE UNDERWATER FIRE CONTROL SYSTEM

Because many operational aspects of specific fire control systems are classified, this section describes in general terms the functions of what may be considered a representative underwater fire control system. The discussion following does not apply specifically to all fire control systems on all ships; the aim is to describe the main elements of most systems in order that the reader will understand their functions and how they work together.

A representative fire control system (FCS) solves the attack problem, generates launching orders, prepares a weapon for firing, develops designation data for tracking a projectile by radar, and provides a means for command to control missile fire. A fire control group consists of (1) an attack console or director, (2) a stabilization computer, (3) a position indicator, and (4) one or more relay transmitters.

ATTACK CONSOLE

The attack console is a computer in the data processing center of the FCS. In addition to receiving target data from sonar, it may be able to act on target bearing and range from missile or gun FC radars.

The console receives information such as (1) own-ship course and speed, and (2) target range, relative bearing, depth, course, and speed. There may be other inputs, depending upon the type of weapon to be launched; most inputs are generated electronically, while others may be inserted manually. The console displays the attack problem on the console geographic plotter section, combining target data with ballistic

and own ship motion to provide (depending on the weapon to be employed)—

1. Generated data for sonar tracking and position keeping.
2. Launcher train and elevation orders.
3. Missile or torpedo set-in orders.
4. Range and bearing for torpedo attacks.
5. Director designation for in-flight tracking.

From received target motion quantities the console computes aided sonar bearing and range tracking information and sends it to sonar. If sonar loses contact, the operator places the console in the position-keeping mode, and attack problem computations continue from the last observed target range, bearing, course, and speed values already entered into the computer.

Depending on what the inputs to the computer are and the weapon(s) to be controlled, the console solves the attack problem and transmits to the weapon the firing signal and the stabilized weapon train angle. (It also transmits to the bridge the course to steer for the attack. (More precisely, it puts out corrections to own-ship course.)

STABILIZATION COMPUTER

The stabilization computer receives roll and pitch data from the ship's gyrocompass, target bearing from sonar, and apparent depression angle from the attack console. From these quantities the computer generates stabilized sonar train and depression orders and transmits them to sonar. Input and output stabilization data are displayed on dial indicators on the front panel of the computer.

POSITION INDICATOR

A position indicator on the bridge provides command with an indication of the source of contact (sonar or radar); a continuous display of own ship, target, and weapon tactical information; an indication of firing readiness; and for some weapons a control by which the commanding officer approves the payload selection. For the last, unless command activates the "approved" control, the attack console cannot generate a firing command.

RELAY TRANSMITTERS

In general, relay transmitters receive input data at a particular frequency, then convert it to a different frequency (operating voltage) for transmission to other equipments. There are many types of relay transmitters depending on the purpose for which utilized. This brief discussion, of course, is concerned only with FCS relay transmitters.

One type of relay transmitter tests, programs, and monitors the ignition and separation assembly data of a selected missile. After the missile is selected, the transmitter tests the power supply, thrust cutoff velocity time channel, and airframe separation time channel to ensure missile readiness for firing. If missile check results are unsatisfactory, another missile must be selected.

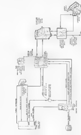
A second type makes the attack console compatible with gun or missile FCSs and weapon direction equipment. This transmitter is used during (1) missile or target tracking and (2) missile designation. For the former, the transmitter converts single-speed synchro target or missile bearing data into two-speed synchro signals for transmission to the attack console. When the transmitter is utilized for missile designation, water entry point quantities and airframe separation time are received by synchro transmissions from the attack console. Designated missile elevation is set in manually.

FIRE CONTROL SYSTEM MK 114

The Mk 114 fire control system (FCS) is used, primarily, to control weapons launched against underwater targets although it can be used to control weapons launched against surface or air targets. A representative Mk 114 FCS is shown in figure 13-18. As illustrated, the system receives inputs from sonar and gun fire control or missile fire control radar for computing target information. (Keep in mind that this is only a representative Mk 114 FCS; other modifications of the system may or may not have the same components as this one.)

The following components make up the Mk 114 FCS:

1. Attack Console Mk 53.
2. Stabilization Computer Mk 134.
3. Position Indicator Mk 78.
4. Relay Transmitters Mk 43, Mk 44, and/or Mk 45.



All units function the same as those described in the preceding section.

FUNCTIONS OF THE UFCS IN AN ASW ATTACK

The ASW attack is one that takes a maximum amount of cooperation between different stations. The attack team includes underwater battery plot, the sonar control room, the conning station, CIC, and the weapon mounts. They are connected by the sound-powered battle telephones.

When a contact is made, it is plotted and evaluated by CIC, which informs the captain on the bridge of the range, depth bearing, and speed of the contact. The captain decides whether to attack and which weapon to use. The sonar operator keeps the sonar on the contact at all times. The attack director operator sets up the director and sets the various inputs for the particular weapon designated. CIC maintains a track of the contact and supplies the director operator with the initial target course and speed.

The attack director operator and sonar operator work closely together until they achieve a solution and so inform the conn and CIC. Conn steers the ship along the course as directed by the attack director and gives the order to fire.

Trainable weapon mounts are automatically driven in train and will follow the solution of the attack director. CIC maintains a plot of own movement. (CIC can be of invaluable help to underwater battery plot by keeping them informed of the direction of maneuver of the submarine.)

There are two types of ASW attacks—urgent and deliberate—and the use of one or the other depends on the tactical situation. An urgent attack is a harassing attack on a submarine and is delivered in the minimum possible time. An urgent attack is made on a submarine which is in position to menace any ship in the body of a force or formation. The urgent attack normally consists of an attack that is destructive in nature and employs all weapons that will bear. Accuracy is usually sacrificed for speed.

Preparation for a deliberate attack begins even while the urgent attack is in progress. A deliberate attack is delivered when the tactical situation allows time to obtain accurate weapon data. The most effective antisubmarine weapon required by the tactical situation is used. The deliberate attack is, therefore, a concentrated attack to kill. Any consideration other than the destruction of the submarine is ignored.

ANTISUBMARINE UNITS, FORMATIONS, AND OPERATIONS

Antisubmarine forces include surface craft, aircraft, submarines, and shore installations. In this section we shall study the ASW capabilities of such units—particularly surface craft—and then briefly investigate how they are used in formations designed for ASW. This discussion is intended only as an introduction, not as a substitute for NWPs and related publications, which are the primary sources of tactical doctrine.

SURFACE CRAFT

Since the advent of modern submarines, the surface ship has been the primary vehicle of antisubmarine warfare. It is now meeting strong challenges from improved submarines and the most advanced ASW helicopters.

A primary advantage of the surface ship is its available manpower. It has more men on board than any other type of antisubmarine craft. This not only allows more efficient operation, but also enables the ship to perform other tasks and functions at the same time that it is engaged in ASW operations. The great versatility of the surface ship also gives it a marked advantage over aircraft and submarines. Additionally, the surface ship has a greater variety of detection equipment: active and passive sonar, radar, ECM, sonobuoys (occasionally), and visual.

Some other advantages and characteristics of the surface ship are (1) a great variety of weapons, (2) the ability to conduct all-weather operation, and (3) a highly accurate and stabilized fire control system. (The accuracy of surface ship fire control equipment is equal to or greater than any other antisubmarine craft.)

These characteristics best adapt destroyer-type vessels (DDs, DDGs, DEs, and frigates) to the following ASW functions:

1. To search for submarines (either on patrol, in hunter-killer operations, or while escorting), to establish their location, and to engage in direct attack upon them.

2. To coordinate ASW attacks with other surface vessels and with aircraft (rotary-wing, or fixed-wing).

The five broad types of ASW operations in which the destroyer-type vessel may engage are:

1. ASW strike operations.
2. Hunter-killer operations.
3. Patrol of assigned areas while continuously searching for submarines.
4. Escort of merchant vessels or other naval vessels not adapted to ASW search and direct attack.
5. Mining.

Larger ships like aircraft carriers and cruisers are not designed to mount ASW weapons. Some of the converted missile cruisers, however, now have Asroc.

The appearance of new equipment and weapons and the modification of their older counterparts have resulted in the demand for more modern versions of ASW units. These may be brand new units or highly modified ships or submarines of our ASW forces. Some examples of ASW units follow.

Many ships of the DD type have undergone improvements through the fleet rehabilitation and modernization (FRAM) program. (Figure 13-19 shows a Forrest Sherman class DD which has gone through the FRAM program.) Included in the program is the latest in ASW equipment such as a variable depth sonar (VDS) and Asroc.

Newer destroyer-type ships such as DEGs, DDGs (fig. 13-20), and DLGs (fig. 13-21) also have the latest in ASW armament.

THE AIRCRAFT CARRIER IN ASW

Carrier task forces are the principal offensive formations of the Navy. The mobile airpower of carriers is used for employment against submarines and their bases, surface ships and their yards, aircraft and their airfields, and for support of amphibious, land, and air operations as well. Its importance in carrying out the mission of the Navy paradoxically makes the carrier an ASW liability because, basically, the carrier has no direct defense against submarine attack. We lost but one attack carrier to submarines in all of World War II. However, if we consider the advances made in submarine capabilities since then, its menace increases dramatically. To take the most devastating conceivable combination potentially available at the moment, we must protect against a fast advanced type of submarine armed with rocketborne target-seeking torpedoes, perhaps

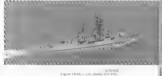


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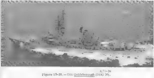
Figure 13-19.—USS Blandy (DD 943).



3.71-20
Figure 13-20.—USS Goldsborough (DDG 20).

134.84
Figure 13-21.—USS Halsey (DLG-23).

with atomic war head. To protect the fast carrier task force against this threat demands inclusion of CVS-type carriers (equipped with aircraft designed for ASW operations), a circular screen of destroyers, an outer screen of submarines, and inner screen of destroyer "pouncers," plus radar picket destroyers, and radar picket submarines. (Figure 13-22 shows such a formation.) The ASW capability of a carrier is in the aircraft aboard, not in the ship itself, although some carriers have AN/SQS-23 sonar sets.

The CVS-type carrier with hunter/killer team is the most effective offensive antisubmarine force yet devised. It will be described later in this chapter.

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Figure 13-22.—Typical task force steaming formation with two aircraft carriers, a cruiser, an
circular destroyer screen.

AIRCRAFT IN ASW

Aircraft, including such fixed-wing types as fighter planes, patrol bombers, and seaplanes, plus helicopters, have the ability to investigate distant contacts rapidly and are completely invulnerable to submerged submarines. However, unfavorable weather can ground aircraft, both carrier and shore based, and high seas can reduce radar and visual detection probabilities to the vanishing point.

FIXED-WING AIRCRAFT (fig. 13-22) have radar and ECM equipment which are effective if the submarine exposes all or part of itself above the surface. Against submerged submarines they can use radio sonobuoys. An experienced sonobuoy operator can distinguish one type of submarine from another and even recognize the type of propulsion plant. Under good sound conditions a sub proceeding at high spe on Diesels has been heard as far as ten mil The use of sonobuoys is restricted, howeve because only a limited number can be carri in the plane. Finally, fixed-wing aircraft ha MAD (Magnetic Anomaly Detection) equipmen but MAD is only effective when the submarine' position is fairly accurately known.

Fixed-wing aircraft can attack submarin with depth bombs (similar in principle to dep charges launched from surface vessels, exc that they are fuzed to explode either hydr statically on reaching a certain depth, or o contact with a solid target). Present doctri includes as a normal method the use of homi torpedoes by aircraft against submarines.

The antisubmarine helicopter is also efficient search unit and is capable of atta as well as detecting and locating. It carri

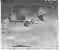


Figure 13-33. — Fixed-wing type aircraft in ASW.

sonar equipment and homing torpedoes. The ASW helicopter mission is to:

1. Detect, track, and destroy submarines, singly or in conjunction with other aircraft or surface forces.
2. Provide ASW search and screening services for task convoy escort, and harbor defense forces.
3. Operate with ASW hunter-killer forces.

SUBMARINES IN ASW

The submarine is itself an effective antisubmarine vehicle. It operates in the same medium with and shares the target's advantages of concealment and passive detection. It can, like the target, take advantage also of the sound refracting properties of sea water, and it can track the target with less distraction caused by this phenomenon. Like the target submarine, it can go deep enough to escape the effects of surface waves and winds. It can hover silent and motionless for long-range passive listening.

The submarine can be employed in protecting the capital ships of a fast carrier task force, in detecting enemy submarines while working with a hunter-killer group, and in supplementing and protecting radar picket destroyers. Submarines can precede a fast carrier strike force into enemy waters to function as antisubmarine screens and as minelayers.

Like any other vehicle, the ASW submarine has limitations. To find the enemy submarine, the ASW submarine must be deep, but to communicate this information to the surface forces it must be shallow. To maintain the silence essential for most effective listening, it must not move. But to get information to someone who can do something about it, the ASW sub must break off the contact or expose its location by surfacing to communicate. And of course, an ASW submarine is always faced with the nerve-racking possibility of being mistaken for the enemy by its own force. These disadvantages will in some degree be overcome by developing new communication methods which will enable the submarine to remain in positive, rapid, and reliable voice communication with the remainder of the force while remaining submerged. Successful multiship coordinated operations depend on reliable communications and the submarine cannot participate until adequate communications have been developed and made available to the forces afloat.

The most effective antisubmarine submarine is the nuclear. These ships have as their strong points the counterparts of the two major weaknesses of conventional submarines. Nuclear ships are fast, whereas conventional submarines must operate at very slow speeds unless they are to be forced to surface or snorkel in a short time.

Furthermore, nuclear submarines can go out and remain submerged on station for extended periods, whereas conventional submarines must have recourse to the surface frequently for battery recharging. Conventional submarines must also withdraw to friendly waters to refuel, unless they desire to take the risk of surfacing in enemy waters to refuel.

ASW SHORE INSTALLATIONS

Shore installations cannot participate in the offensive ASW operations that the mobile units so far mentioned can perform, but they have important defense functions. They have cognizance over harbor defense submarine-detection systems using radar, sonar, magnetic loops (large rectangles of cable laid across the ocean floor which detect any distortion of the earth's magnetic field caused by an iron or steel body crossing the cable), heralds (a passive sonar system), hydrophones, and sonobuoys. Nets and mine fields are used in actually blocking submarines and torpedoes.

An ideal harbor defense detection system consists of magnetic detection loops (or early warning hydrophones) to seaward, hydrophones or sonobuoys to back up the loops, and heralds (long-range operator-controlled sonar near the approaches to the harbor, and short-range sonar units guarding the inner harbor). Surface and air patrols are responsible for the ocean areas to the approaches of the harbor.

ANTISUBMARINE OPERATIONS

Since we are primarily interested in ASW as it relates to destroyer type surface vessels, let us consider briefly those types of ASW operations in which such vessels participate. These are the ASW strike, hunter-killer operations, ASW patrol and search and protective escort or screening. (Destroyer vessels also perform ASW mining, but this operation does not involve ASW detection equipment or weapons and is not taken up in this text.) The limited general discussion to which this text is confined is not

to be considered a substitute for study of doctrinal publications such as NWPs, NWIPs, and related instructions issued by such authorities as CruDesLant.

ANTISUBMARINE STRIKES

The ASW strike can be considered the remedy to the submarine problem. Just as it is more effective to destroy the breeding places of disease-bearing mosquitoes than it is to swat at them even with very efficient swatters, it is more effective to destroy or reduce the enemy's ability to fabricate submarines than to attempt to destroy those already at sea. Even the most efficient ASW campaigns of the past did no more than keep the enemy submarine population in check.

ASW strike operations are offensive operations directed against bases and installations which produce and maintain enemy submarines. If successful, they not only reduce or prevent production of submarines, but also make it progressively more difficult for the enemy to keep in service the submarines he has.

ASW strikes differ substantially from other attack operations only in the nature of their targets.

HUNTER-KILLER OPERATIONS

A hunter-killer (HUK) operation is a sustained ASW search and attack by an organized group of naval units in an area in which submarines are thought to be located. Any combination of ASW ships and aircraft may be used.

In the typical hunter-killer operation the CVS-type carrier, screened by five or more destroyers, will employ embarked fixed-wing ASW search aircraft and helicopters in an offensive search patrol. When either the aircraft or the surface screen contacts a submarine, the detecting unit will become the contact area commander (CAC), and a search attack unit (SAU) of at least two destroyers will be detached to assist in the development of the contact. In the meantime, the aircraft will attempt to develop the contact in an effort to localize and destroy the submarine. If initial detection is accomplished by visual sighting, radar detection, or possibly by MAD or ECM (electronic countermeasures) gear, it will be localized by employment of electronic countermeasures such as sonobuoys (fig. 13-13). If the target position can be accurately located, the attack aircraft may attack with one of its weapons such as an atomic or conventional depth bomb, homing torpedoes, or rockets. Decision as to who takes command in the contact area is made on the spot and it can change from one unit to another as the situation develops. Generally, it rests in the unit with the best over-all picture of the situation or the strongest contact with the submarine.

Hunter-killer operations are divided into three phases.

1. The extended search by aircraft, resulting in a contact and attack on the submarine by aircraft.
2. The approach of the SAU to the submarine contact area (datum) to cooperate with the aircraft, if the aircraft attack has failed.
3. The local search and attack by a search attack unit (SAU) in cooperation with the aircraft.

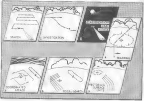
Once a contact has been definitely established as an enemy submarine it must be attacked until destroyed.

Figure 13-24 shows schematically the sequence of operations in one type of attack. In part 1, fixed-wing aircraft conduct a systematic search of the area, finally detecting a surfaced submarine by radar. Next, as its status and identity are investigated, the submarine dives, and the aircraft drops a group of sonobuoys so that it can keep tracking the submerged target while it calls in surface units of the hunter-killer group and directs (vectors) them toward the sub. By this time it is necessary to reestablish the location of the submarine. The ships and aircraft do this in cooperation. The ships search by sonar; helicopters may use dunking sonar units; the other aircraft may drop more sonobuoys. When the target submarine is located, the ships attack, using depth charges, rockets, homing torpedoes, and such other weapons as are considered appropriate.

This attack pattern is more or less typical, and variations of it apply in the other operations described below.

ASW SEARCH

ASW search is the systematic observation by ships or aircraft of a particular area where submarines are thought to be located. Ships are more effective at detecting submerged submarines, but are much slower at it because



38.40
Figure 13-24.—Hunter-killer operation, Schematic.

of their relatively low speed (compared to aircraft) and limited radius of visual and radar coverage. Two or more ships usually work together in search because they can provide mutual support in an attack and because a submarine can evade two ships only with much more difficulty than it can evade one.

Fixed-wing aircraft can survey a wide area relatively quickly, and can efficiently detect surfaced and snorkeling subs, but their ability to locate submerged submarines is quite limited. Such devices as sonobuoys are effective at tracking submerged submarines only when they have been dropped fairly close to the submarine. However, search by fixed-wing aircraft has the additional advantage of forcing submarines to keep submerged; this can handicap a conventional submarine's operations.

Helicopters can use dunking sonar to search actively for submarines.

ASW PATROL

An ASW patrol operation is a systematic and continuous surveillance along a line, either stationary or moving, to detect submarines attempting to cross it. Patrol operations are actually closely related to search, and similar methods are used. Figure 13-25 illustrates the distinction between patrol and search.

ESCORT OR SCREENING OPERATION

To provide maximum protection against enemy aircraft and submarines, during wartime ships do not traverse the open sea singly, but

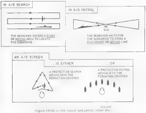


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Figure 13-23. — ASW search and patrol, schematic.

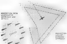
in groups. A formation of naval vessels is called a force; a formation of merchantmen is a convoy. Around the group to be protected is a screen made up of destroyer-type vessels, and an area constantly being patrolled by aircraft. The screen is concentrated in the forward part of the formation. Figure 13-26 shows in simplified schematic form how a screen protects a convoy. Figure 13-22 is a photograph of a task force and screen.

DESIGNATION OF ASW FORCES

Forces to conduct ASW operations are designated in accordance with their mission. A force assigned to locate and destroy submarines at sea may be designated as a search, patrol, or hunter-killer force. A force assigned to close an enemy submarine base, or to close a strategic strait to enemy submarines, may be designated a mining force or a patrol force, according to the type of operation. A force assigned to protect shipping at sea against enemy submarines may be designated as ASW search, patrol, escort, or support force, depending on the type of operation. A screening unit can be part of a force, or it can be designated as an escort force. The list can be extended to include forces for the defense of harbors, fixed sea areas, or a coastal area.

EMPLOYMENT OF ASW FORCES

In addition to protecting a fast carrier task force (as mentioned previously) an ASW force may be used in various numbers and combinations for antisubmarine operations. This text



110.117
Figure 13-26.—ASW escort operations. Schematic.

will take up singleship, multiship, and hunter-killer antisubmarine tactics.

SINGLESHIP ASW ATTACKS

In determining whether to make an urgent attack or a deliberate attack, the commanding officer or the OOD must consider the tactical situation and make a decision almost immediately upon sonar contact. The considerations for arrival at this decision are stated in Allied Naval Maneuvering Instructions (ATP-1) and in NWP 24. In general, the considerations depend upon the assigned task of the ship gaining contact and the degree of immediate threat to protected ships, own ship, or other ships in company.

Although an initial contact may be made while the ship is at general quarters, it is more probable that the normal cruising watch will be set. In a normal cruising watch, sonar control is manned by an ASW watch officer (supervisor), search sonar operator, and standby operator. The sonarmen assigned to a cruising watch must be capable of controlling any type of ASW attack on a submerged submarine, must be able to evaluate any evidence of submarine counterattack, and have sufficient tactical knowledge and ability to recommend course changes and maneuvers. Sonar is usually the only ASW station manned in a normal cruising watch. (This of course does not include the OOD or CIC officer.)

The members of the general quarters ASW attack team man their stations as soon as possible after initial contact is made. At the moment contact is made on an enemy submarine it is imperative that every effort be made immediately to gain the advantage and exploit it by attacking until the submarine is sunk. If the contact is in a position to menace any ship in the main body of the force or formation, an urgent attack is immediately delivered. Deliberate attack follows when the formation is no longer in immediate danger.

Tests at sea have demonstrated that with favorable sonar conditions a single ASW ship, capable of 27 knots or more, and equipped with high-power low-frequency sonar, can hold contact on a freely evading high-speed, deep-diving submarine. Ship's ASW attack speed, however, is commensurate with the ship's effective sonar speed (normal around 20 kts.) These tests have demonstrated that a single ship can attack and repeatedly reattack with Asroc and similar stand-off weapons with much greater maneuvering safety than she could if another ship were in close proximity. However, the principle of mutual support makes it desirable to have a second ship in the vicinity ready to be called in to take over the attack.

When ASW attacks are to be by ahead-thrown weapons, rocket-assisted missiles, or stern depth charge, the safety of friendly aircraft is a prime consideration. Low-flying aircraft such as MAD equipped planes or helicopters using dip sonar may be endangered when the ASW ship uses such weapons.

MULTIPLE SHIP ASW ATTACKS

Initially, ASW was effected by singleship attacks. The ASW attack was a battle of ship against boat and captain against captain. Experience taught us that the exchange rate of surface ship for submarine was too costly. A more efficient and successful method of attack was required. Finally, tacticians evolved the concept of the multiship attack. By constant training and experimentation, well-defined and effective multiships tactics have been developed.

A multiship ASW action is any ASW action involving two or more ASW ships maneuvering to a prescribed plan. The plan is designed to maintain the offensive by maximum rapidity of attack and continuous contact on the submarine. It is employed to maximum effectiveness in close-in attacks when two ships using ahead-thrown

weapons work the submarine over until it is destroyed, or contact is lost and cannot be regained, or the ASW action is terminated by higher authority. Successful two-ship coordination depends on rapid and reliable voice communications and complete exchange of information and intentions. Additional ships if available are employed as supporting ships by putting them on a circle around the contact or on a fence prepared to take over the attack or commence a search if contact is lost.

The new concept in ASW employs the long-range, standoff technique. This of course is due to the recent and continuing development of long-range ASW weapons, such as Asroc and Subroc. The destruction of submarines at long range is desirable; however this ideal situation will not always be possible. Thus, single and multiship ASW attacks may still be used when the situation arises.

FUTURE OUTLOOK

No individual piece of equipment or type of weapon can solve the ASW problem. Now, and in the future, the task group commander must employ his various ASW units, either singly or in a combination, to attain their greatest advantage. Each type of ship, submarine and aircraft has its particular function; each has its definite limitations. For example, a destroyer has great underwater tracking and attack ability against enemy submarines, but is limited in speed; moreover, its performance is hampered considerably by rough seas. By the same token, the submarine is a superb sonar-detection vehicle, and can operate deep enough to escape adverse sea conditions that plague surface ships. Diesel submarine endurance capability, unsupported, approaches 60 days. This exceeds that of any conventionally propelled destroyer type. Nuclear types of course far exceed this figure.

Constantly weighing the array of weapons at his disposal, the task group commander selects the one (or the combination) that best accomplishes the task at hand.

Tactics will change with new developments of detecting equipment and weapons. Today, however, and in the near future, it still will require the combined efforts of all types of ASW units to meet the submarine threat.

Our ASW forces of the future will include many ships and weapons unfamiliar to us now. But the most advanced hardware, alone, will never assure victory. At the base of the tactical problem are the officers and men who will put this hardware to use.

CHAPTER 14

ORGANIZATION AND COMMUNICATIONS

The military potential that any modern U. S. combat ship possesses is a function not only of the trained personnel and powerful armament aboard, but also of how they are organized to accomplish the mission the fleet has assigned to them.

In the preceding chapters, you learned the fundamentals of the "conventional" weapons that make up the modern U.S. Navy's shipborne arsenal. This chapter presents the fundamentals of shipboard battle organization on combat ships, and briefly describes the communications system through which the ship's fighting potential is coordinated for its most effective employment.

FUNDAMENTALS OF SHIP'S ORGANIZATION

Any ship's organization is based fundamentally on instructions issued as NWPs by the Chief of Naval Operations, particularly NWP 50, Shipboard Procedures, and NWIP 50-1, Battle Control. Standard organization manuals issued by Atlantic and Pacific Fleet type commanders (e.g., Commander, Cruiser-Destroyer Force Atlantic) follow these CNO instructions as a guide, and individual ships set up their organization structures in accordance with these. An individual ship's organization is promulgated in the Ship's Organization and Regulations Manual and the Battle Organization Manual. Other organization media such as charts and posted ship's bills are based ultimately on these sources. For details on shipboard organization not discussed in these pages, consult these sources.

A ship's organization may be based on its complement or its allowance. The complement includes the officers and men (by number, rank, and rate) assigned by the Chief of Naval Personnel to the ship in time of war. The allowance (a smaller number) itemizes the personnel assigned to the ship in peacetime. (The actual population of the ship is the on-board count or manning level; this may be yet another number, or it may correspond to the complement or the allowance.)

In compliance with NWPs, a ship's organization normally is set up in five major parts—the battle bill, the administrative organization, the watch organization, the organizational bills (administrative, operational, and emergency), and the ship's regulations. We are here primarily concerned with the ship's organization as it functions in battle (or simulated battle and related operations; from this point of view the most important parts of the organization are the battle bill and some parts of the organization bills.

A bill, by the way, is a written directive that prescribes a procedure for performing some operation, such as berthing the ship, or for dealing with some specific situation or emergency, such as fire, or for performing battle operations. A bill lists the things to be done, the material needed, and who is to take action. It identifies these last not by name but organizationally by billet or other organizational designation.

PURPOSES AND PROMULGATION OF BATTLE ORGANIZATION

The purpose of the battle organization of any ship is to:

(1) Organize the ship for battle and for wartime cruising by assignment of personnel to ship stations under the various prescribed degrees of readiness.

(2) Define communications between battle control stations within the ship, and provide information on interior communication system.

Type commanders, under the direction of fleet commanders-in-chief, are not only responsible for furnishing to ships of the type and

appropriate outline of battle organization, but also for coordination between commanders of the same type in different fleets. This assures a practical uniformity of battle organizations for all ships of a type. Thus, interchange of personnel between ships or of ships between fleets does not present a major problem.

BATTLE CONTROL STATIONS

The key elements of a ship's battle organization are the battle control stations. The commanding officer must rely on officers at battle control stations for the execution of his commands. Most primary stations control secondary stations.

The eight primary battle control stations in combat ships of the Navy include:

1. Command control
2. Ship control
3. Operations control
4. Primary flight control
5. Weapons control
6. Engineering control
7. Damage control
8. Mine countermeasure control

Figure 14-1 shows communication lines between primary and secondary control stations. Since the diagram is a general one, it applies to specific types of ships only insofar as the type possesses the elements concerned. Primary flight control, for example, obviously doesn't apply to a destroyer. However, the organizational principle of using primary and secondary battle control stations as key points or nuclei about which the battle organization is constructed applies universally.

COMMAND CONTROL

Command control is exercised by the commanding officer at his battle station, which may be on the bridge or in commanding officer's tactical plot. From this station he directs the ship's course of action in battle by exercising control over all the primary battle control stations. Matters of paramount importance to the commanding officer during battle are the orders of his seniors in tactical command, conditions within the ship that affect his ability to carry out those orders, and information on external developments which have a bearing on the battle. His main responsibilities are to inform primary battle control officers of his objectives and to render decisions in matters having major influence on the combat effectiveness of the ship.

SHIP CONTROL

Ship control is under the immediate direction of the officer of the deck who is located on the bridge. The main functions of ship control are:

1. Conning the ship, as ordered by the commanding officer.
2. Maintaining operational control of tactical maneuvering communications.
3. Keeping other battle control stations informed of ship's maneuvers, present and anticipated.

Ship control receives direct assistance from CIC, commanding officer's tactical plot, a navigation detail, a signal detail, tactical voice radio operators, lookouts, steersmen, telephone talkers, and messengers. An efficient and dependable ship control aids command control by permitting the commanding officer to concentrate on the larger problems in fighting the ship.

OPERATIONS CONTROL

The primary objective of operations control is to assist command control in planning the correct course of action and to assist command and key battle control officers in executing that plan. Operations control is collectively applied to those activities under the cognizance of the ship's operations officer, which are:

1. Communications control
2. Air operations
3. Aircraft control
4. Electronics casualty control
5. NTDS casualty control
6. Information control
7. ASW control
8. Weapons coordination

Operations control emanates from the ship's CIC which, on many ships, is the operations officer's battle station. The principal battle functions of operations control are to:

1. Keep command control informed of the tactical situation.

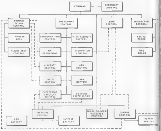


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Figure 14-1. — Representative battle organization chart.

2. Assist ship control in carrying out its functions.
3. Perform operational evaluation.
4. Operate voice radio circuits.
5. Conduct radar search, identification, and tracking.
6. Analyze and/or conduct electronic countermeasures.
7. Plan operational schedules for aircraft (aboard aircraft carriers).
8. Perform aircraft control duties.
9. Assist sonar search and tracking (ASW ships).
10. Perform combat intelligence duties.
11. Assist weapons control in target acquisition and designation.
12. Assist torpedo control in solving torpedo attack problems.
13. Obtain weather and aerological data.

PRIMARY FLIGHT CONTROL

Primary flight control consists of the control of shipboard aircraft handling and those operations incidental to launching and recovery of aircraft. During flight operations, the air officer is responsible for those operations, as well as the visual traffic control related to these functions. The air officer's battle station is primary fly. He receives his orders here directly from command control. During routine flight operations, the assistant air officer is

also stationed at primary fly. Under battle conditions he is at secondary fly.

WEAPONS CONTROL

Weapons control is under the direct and positive control of the weapons officer. The weapons control station (fig. 14-2) provides centralized coordination and monitoring of missile systems and gun batteries. Located here is the equipment which furnishes displays and controls for selecting and tracking targets, for evaluating and processing data, for assigning targets to fire control systems, for loading the launcher, and for firing missiles at the optimum time.

Target indications are presented on the target selection and tracking consoles. The selected targets are tracked by operators and the target data sent automatically to a director assignment console. Here the relative threat of the targets is again evaluated, priority of engagement determined, and assignment of a missile or gun fire control director made. At the same time, loading of the launcher is ordered for the top priority target from the weapon assignment console if director assignment has been made to a missile fire control system. Targets unsuitable for missile engagement are assigned to gunnery fire control equipment for separate processing.

ENGINEERING CONTROL

Engineering control is the engineer officer's battle station. Located at main engine control or a central control station, he supervises control of the main propulsion plant and auxiliary equipment.

The principal battle functions of engineering control are to:

1. Supervise the operation and maintenance of the main engineering plant.
2. Exercise casualty control procedures.
3. Keep command control informed of the main engineering plant casualty status.
4. Assist damage control in such functions as flood control, maintaining stability and trim, fire fighting, damage repair, and maintenance of watertight integrity.

DAMAGE CONTROL

The Damage Control Assistant (DCA) exercises control from his battle station in damage control central. On some ships damage control central is located in a central control station with engineering control. On other ships it is in a separate compartment of its own or at a designated repair party station.

The damage control battle organization is composed of damage control central; repair parties for hull, propulsion, weaponry, and air; and battle dressing stations. The weapons department, among others, is responsible for control of damage to its own equipment. There must be no doubt in the minds of the ship's personnel as to who is responsible for taking either normal or emergency action for damage control. Each officer and man must be familiar with the damage control organization of his ship and his own responsibilities to it.

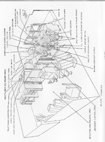
There are two principal phases of damage control. They are the preventive phase and the action phase. The preventive phase begins with the preliminary design of a ship and continues through the construction, organization, maintenance, and operation of the ship. Efforts on the part of all departments in maintaining material readiness, training of personnel, and exercising readiness doctrine help place the ship in the most favorable condition to withstand damage. The action phase begins after the ship is damaged. This phase requires the damage control battle organization to take steps to promptly restore the offensive and defensive potential of the ship. The action taken is the cumulative result of the training and material preparations conducted during the preventive phase.

MINE COUNTERMEASURES CONTROL

Mine countermeasures control is a collective term applied to all minesweeping and minehunting functions which are within a ship's capability to perform.

Minesweeping procedures consist of sweeping an area of water for mines, either by covering it or traversing it with mechanical or explosive gear which physically removes or destroys the mines or by producing the influence fields necessary to actuate the mines. Direct control of minesweeping operations is exercised by the mine countermeasures officer whose battle station is on the bridge or in CIC except when actually using or recovering minesweeping gear, at which time he is on the fantail.

Minehunting includes all measures for detecting, accurately locating, identifying, and clearing mines individually. This clearance may be accomplished by explosive destruction, rendering mines safe and disposing of them, or


DETECTION AND TRACKING AREA
ORDNANCE CONTROL AREA

by sweeping. Overall control of minehunting functions is exercised by the operations officer, whose battle station is in CIC. Mine disposal is the function of qualified Explosive Ordnance Disposal personnel and is under direct control of the officer in charge of the EOD team.

Channel conditioning, which includes all measures for the clearance of mines and mine-like objects in areas and channels planned to be used in time of war, is a part of minehunting when not specifically assigned to an EOD team.

BATTLE ORGANIZATION IN U.S. NAVY SHIPS: OPERATIONAL ASPECTS

During battle there seldom is time for lengthy consideration of the problems presented. To arrive promptly at a satisfactory solution, it is necessary that the more probable contingencies be anticipated and provided for. A basic weapons doctrine in writing, promulgated by the type commander, helps prepare the ship to:

1. Overcome surprise.
2. Develop maximum effective fire power in a minimum of time.
3. Make use of all automatic features of the equipment provided.
4. Simplify methods of control and provide each echelon with a clear-cut delineation of responsibility and authority.
5. Ensure automatic and instantaneous shift to secondary or auxiliary methods, with the replacement of personnel as necessary in the event of casualty or damage.

In concrete terms, weapons doctrine for his ship gives to a junior officer acting as director officer (or in some similar station) instantaneous guidance in answering and acting upon such urgent questions as the following—questions that demand quick action when you're faced with what may well be a genuine enemy target:

1. Must I get the captain's permission to open fire?
2. At what range may I open fire?
3. If there are several targets, how do I decide which to fire on first?

And there are many other decisions that your ship's weapons doctrine is designed to guide you in making when your ship is in action. Weapons doctrine specifies not only what you are to do in any of a number of given circumstances, but also indicates what you may expect of others, as well as what others expect of you. On any U.S. Navy ship you will find a special file or compilation of weapons doctrine, which you are expected to learn and follow without delay. Your ship's doctrine is in turn based on more general doctrine to be found in NWIP 30-1 and in directives issued by type commanders and other competent authorities.

THE SECTION AND THE BATTLE BILL

The primary organizational unit of the ship for administration, watch standing, and liberty is the section. Each division is broken down into three approximately equal sections, each completely adequate to maneuver and fight the ship within the limitations of the available personnel. Each ship assigns an adequate number of properly rated and qualified men (assignments are shown on the watch, quarter, and station bill) to man stations for any eventuality, including the stations for getting underway (Special Sea and Anchor Detail) and proceeding to sea for limited operations, as may be required by weather, surprise hostile activity, or other emergency situations.

Assignment of all personnel to individual battle stations is made in the battle bill, which is in chapter 3 of each ship's Battle Organization Manual. Officers are assigned by billet (job title). Enlisted personnel are assigned by billet number. A billet number is made up of a series of numerals, or a combination of letters and numerals, which indicate a man's division, his section, and (usually) his seniority or precedence in his section. As an example:

Billet No.	Description
1-204 - - - - - - - - -	1st division, 2nd section, 4th in seniority.

The battle bill lists the stations which must be manned under battle conditions and indicates the personnel requirements for manning those stations. The numbers, ranks, and rates of personnel assigned to battle stations by the battle bill should agree with the ship's wartime complement and peacetime allowance lists. The battle bill's summary is useful to division officers when making up the division watch, quarter, and station bill.

WATCH, QUARTER, AND STATION BILL

The watch, quarter, and station bill is the division officer's summary of the assignments of personnel to duties and stations specified in the battle bill and in each of the other ship's bills, which are contained in the ship's Organization Manual. One of the goals of the bill is to attain a smooth transition from one condition watch to another, thereby eliminating confusion and conflict of watches. Its primary purpose is to inform division personnel of their assignments. Technically, this is considered accomplished when it is posted on the bulkhead in the division. In practice, the division officer should disseminate this information to the men in his division, especially where there is a large proportion of new men.

The watch, quarter, and station bill shows for each billet the name and rate of the individual assigned, the station he is assigned for cleaning and maintenance, where he is quartered, his assignments in all condition watches (including Condition 1 or General Quarters—this is his battle assignment), and his assignments in specific operational and emergency bills. Figure 14-3 shows a common form of this bill in which the assignment information is entered on cardboard strips that slide into grooves in the billboard.

CONDITIONS OF READINESS

Conditions of readiness is a general descriptive phrase referring to a ship's ability to meet the preparedness requirements for combat. An Officer in Tactical Command (OTC) may order a condition of readiness for any of the following requirements: amphibious assault, antiaircraft, antiship, antisubmarine, damage control, engineering, or aircraft. Conditions of readiness do not describe any particular combat situations and do not establish a specific watch organization and operational arrangement. The phrase is frequently incorrectly used as if it were synonymous with either degree of readiness (discussed next) or condition watch (discussed later).

DEGREES OF READINESS

The objective of all watch organizations is security of the ship for all probable conditions. Secondary to this objective is the need for an optimum degree of efficiency in administration of the ship. To maintain such security, or readiness, and ensure the needed efficiency, requirements for specified degrees of readiness are set down. The amount of security furnished the ship is normally adjusted to the demands of the current situation by use of the six general degrees of readiness, which are as follows:

1. Complete readiness for immediate action.
2. Temporary relaxation from the first degree of readiness to enable personnel to rest and to permit designated personnel to draw and distribute action meals at their action stations.
3. A part of the armament ready for immediate action, the remainder on short notice.
4. A part of the armament ready for immediate action, the remainder at prolonged notice.

DIVISION					
NAME	RATE	BERTHING & LOCKER		CLEANING AND MAINTENANCE	BILLET NUMBER
		LIVING COMPARTMENT	BUNK & LOCKER NO		
D. L. JOHNSON	BMC	A-300L	11-12	IN CHARGE	3-101
E. HAMILTON	BM 2	C-205 L	11-2	IN CHARGE MAIN DECK PORTSIDE	3-102
P. L. KELLY	SN	C-205 L	7-3	AFTER CREWS HEAD	3-103

76.5
Figure 14-3. —Part of watch, quarter, and station bill.

5. Peacetime cruising—no armament manned.
6. No armament manned, ship in port under peacetime conditions.

The general degrees of readiness, as described above, define the nature of the tactical situation in terms of the probability of attack and/or battle action and relate this situation to the combat capability of own forces required to meet the threat. General degrees of readiness apply to the WHOLE UNIT, whether an individual ship or a task force.

Particular degrees of readiness delineate the specific requirements for the battle organization components with an INDIVIDUAL UNIT. Condition watches are derived from the particular degrees of readiness.

A modification of a particular degree of readiness is assumed by the amphibious types for the conduct of amphibious operations. This is evidenced by their addition of a condition called 1A (one alpha). It represents an entirely different organization which is used to embark and debark amphibious troops and equipment.

CONDITION WATCHES

The condition watches established in the watch, quarter, and station bill are derived from the particular degrees of readiness promulgated in the Battle Organization Manual. Condition watches apply to specific shipboard watch organizations which satisfactorily meet the degrees of readiness prescribed in certain situations. They provide the optimum personnel/operational combination. The following tabulation shows the condition watches associated with each general degree of readiness.

General degree of readiness	Condition watch
First	I
Second	IE
Special or third	II
Fourth	III
Fifth	IV
Sixth	V

Battle readiness includes conditions I, IE, and II. Under condition watch I, for example, all ship's personnel man their individual battle stations. Condition I corresponds to General Quarters the full battle readiness condition. Under condition watch IE, the requirements are relaxed enough to permit the men to have their meals and brief relief periods at staggered intervals. Condition II includes two general degrees of readiness, special and third. The special degree of readiness is for limited action; the third degree of readiness is in effect when part of the armament is ready for immediate action, and the remainder is on short notice.

Condition watch III corresponds to a state of wartime cruising readiness. Ship's personnel man the wartime cruising watch stations, including part of the ship's armament, on a one-watch-in-three basis.

Condition IV is used for peacetime cruising. Condition V is for in-port, peacetime conditions.

INTERIOR COMMUNICATIONS

A reliable and easily operated interior communications (IC) system is essential to the functioning of the battle organization. Through the IC system, command control directs all elements of the ship's combat power; primary control stations pass orders and reports; and subordinates exchange information necessary to perform their duties.

The signals transmitted in IC systems include (1) verbal transmission by voice or legible words, (2) nonverbal audible or visible signals (such as alarms) intended for personnel, and (3) electrical signals (such as synchro signals or relay currents) to be received and utilized directly by electrical or mechanical devices. This section is not concerned with the third type of signal, which has been already discussed in connection with the functioning of fire control systems.

VERBAL IC SYSTEMS

The number and complexity of verbal IC systems aboard a ship depend upon its size, type, function, and communications needs. However, on all ships the systems are organized along parallel lines, and similar code designations are used, so that, for example, the 1JV sound-powered phone circuit aboard a light cruiser has its counterpart (though somewhat simplified, because the ship is itself less complex) aboard a destroyer, and is almost identical with its similarly designated circuit aboard another ship of the same class.

The principal verbal IC systems aboard combat ships that will be studied in this section are:

1. Battle (sound-powered) telephones.
2. Announcing (MC) systems, both one-way and multichannel.

Other systems are also used, but are relatively less important in weapons operations. These include the ship's service dial telephone, voice tubes, messengers, pneumatic tubes (to carry written messages), Teletype systems (with large-screen projection of the printed tape at the receiving point), Telautograph, special telegraph systems like the engine room telegraph, and closed circuit television.

BATTLE (SOUND-POWERED) TELEPHONE SYSTEMS

The most important IC system is the sound-powered battle telephone system, in which the speaker's voice creates the power that transmits the message. No outside source of power is required. This system is therefore more reliable in emergencies than any that depends upon electric power supplied externally.

Battle telephones are set up as groups of connected stations rather than as individual stations. When a telephone is plugged into its jackbox it is automatically connected with all other stations that are plugged into that circuit. The connected groups are called circuits. Circuits in turn are organized into systems: (1) primary, (2) auxiliary, and (3) supplementary.

There is a standard method of designating, by symbols, every circuit in each of the three systems. The primary battle telephone system uses circuit designations JA to JZ. Typical examples are:

JA — Captain's battle circuit
JC — Weapons control circuit
JK — Fuze setters' circuit
JW — Range circuit

Numerals preceding the two-letter designations (2JW) are used to identify individual circuits with the same function but pertaining to different batteries (or similar subdivisions for nonweapons circuits). Numerals following the two letters indicate stations on the circuit. For example, 2JW2 refers to a particular battery's range circuit, station 2.

Auxiliary battle telephone circuits are assigned circuit numbers similar to their primaries, but preceded by the letter X; for example, XJA for the captain's auxiliary battle circuit, or X1JC for the auxiliary turret control circuit. Circuits of the supplementary telephone system are assigned designations such as X1J and X2J through X407J.

PRIMARY CIRCUITS

Primary circuits are the main channels of communication for controlling armament, engineering, damage control, and maneuvering of the ship. When the ship is at general quarters, each station on a primary circuit is normally manned by either the officer in charge of the station, one of his assistants, or a telephone talker reporting to the officer in charge of the station. These men normally wear headsets, so that they may maintain a continuous watch on the lines. In addition to those headsets which are plugged into individual circuits, control officers may wear headsets which are connected to selector switches which enable them to cut into any one of several circuits in which they are directly interested. At other stations control officers may have available to them handsets with which they may intermittently communicate on one or more circuits normally covered for them by talkers. (A talker is an enlisted man assigned, as a principal duty, to man a battle phone station for an officer at a control station.)

All primary circuits for the ship's armament can be controlled and interconnected by switchboards in the plotting rooms, as well as by selector switches. With these switchboards, control circuits may be shifted to parallel the transmission of information or orders by synchro. They also make it possible to tie circuits together, as may be done during wartime cruising when not all stations are fully manned, or to provide emergency communication facilities between stations not normally connected, and to isolate circuits or individual stations when necessary as, for example, in case of casualty.

In the plotting room a Fire Control Technician is normally assigned to the fire control switchboard, and an I.C. Electrician to the battle telephone switchboard. When control is switched from one station to another, they reset both boards. This means changing over the synchro and indicator circuits of one or more batteries to connect them to one or more other batteries. The ordnance control telephone circuit (JC) must be switched likewise. This is done by making

cross-connections on the switchboards. The personnel in the plotting room take care of the plugging and switching involved. Personnel in the director and at the guns know what is going on, but they play no part in the actual switching operation. The I.C. switchboard crew takes care of interconnecting other affected circuits as required.

AUXILIARY, SUPPLEMENTARY, AND EMERGENCY CIRCUITS

The auxiliary battle telephone system is a standby system which duplicates the most important primary circuits and is intended for use in case the latter become inoperative. It does not have switchboards. Therefore, in case of a casualty at the switchboard, the auxiliary circuits may still be available for use. The wiring of the auxiliary circuits is separated as much as practicable from the wiring of the corresponding primary circuits to prevent battle damage to both circuits. As the auxiliary battle telephone circuits are not ordinarily continuously manned, they are generally equipped with handsets and receptacles to connect headsets, when necessary.

Supplementary circuits are those either not important enough or not extensive enough to be included in the primary system. Most supplementary circuits include only two or three stations. They are equipped with handsets and are usually accompanied by circuit-E buzzer systems. In mounts and turrets most supplementary circuits are concerned with ammunition service. Thus, the supplementary circuit found in 5-inch enclosed mounts is the X17J, which connects the top and bottom of the lower ammunition hoists. Turrets may have more elaborate supplementary telephone circuits for internal use. The Salem class 8-inch turret has nine supplementary circuits. One of them connects the turret officer with gun positioning and sight-setting personnel, and the others connect various stations of the ammunition supply system with the gun captains and turret officer. Supplementary battle circuits have no switchboards, but selector switches can be used to interconnect some supplementary circuits or to tie them into primary circuits.

Emergency sound-powered systems consist of portable telephone lines with sound-powered telephones attached. This emergency equipment is generally kept on reels located at strategic points throughout the ship and the phones may be unreeled to serve as a standby in case of failure of normal sound-powered communications during battle.

BATTLE ANNOUNCING (MC) SYSTEMS

There are two characteristic types of battle announcing systems. One is the central amplifier system, consisting of one or more microphones and loudspeakers. The other type is the intercommunications ("intercom") system, designed to provide two-way transmission of orders and information between stations. Both types use electronic amplification.

The main announcing system for the ship is the 1MC, or general announcing system operating under the authority of the Officer of the Deck, over which word can be passed to all parts of the ship.

The 21MC is the captain's command announcing system. This system provides for two-way transmission of ship control orders and information between interested key stations, including the primary and secondary conning stations, battery control stations, air defense stations, combat information center, and others. Other electronic amplification systems of interest to weapons personnel are listed in table 14-1.

Central amplifier type MC systems have an advantage over telephone communications in that they transmit orders or information simultaneously to all personnel at a station. Since, however, their continued use results in excessive noise levels, they are normally employed only for urgent and simple messages.

Intercoms, like general announcing systems, have the advantage of attracting the attention of all hands at a station simultaneously. They similarly have the disadvantage of raising noise levels, although this disadvantage is lessened by the fact that messages are heard only at the one station addressed. They are used to parallel telephone communications in the case of urgent and short messages, and are also frequently used to regain communications when a station fails to answer on a battle telephone circuit.

The sound-powered telephone system has been adapted, in certain cases, so that when desired, the voice on the sound-powered telephone circuit can be electronically amplified and put through speakers. Such a combination of the battle telephone with electronic amplification has the advantages of an intercom and a

Table 14-1. — Weapons announcing (MC) systems

CIRCUIT	SYSTEM	USED PRIMARILY O
	Central Amplifier Systems	
29MC	Sonar Control Information	Surface Shi
46MC	Aviation Ordnance and Missile Handling	Aircraft Carrie
	Intercommunications Systems	
27MC	Sonar Control	Submarine
30MC	Special Weapons	Aircraft Carrie
32MC	Weapons Control	Surface Shi
47MC	Torpedo Weapons Control	Submarine

110.163

telephone. It is used primarily at battery control stations for communications to gun mount personnel. This has replaced MC systems in these stations on most all ships.

SIGNAL SYSTEMS

Telephone and announcing systems are primarily voice communication systems. Besides these, modern combat ships are equipped with several systems of signals for special purposes:

1. Train Warning Signals. Safety regulations require that before any turret or enclosed mount is moved in train, a warning signal must be sounded so as to inform personnel to keep clear. The only exception is that the signal need not be sounded during general quarters. The train warning signal circuit is independent of all other IC circuits, and consists of a pushbutton control switch at the mount captain's station, bells outside the mount, and the necessary wiring and power supply.

2. Call-Signal System (circuit E). The call-signal system (circuit E) parallels the supplementary battle telephone circuits and voice tubes. It is not used independently; it always parallels a voice communication line. It consists of power-supply units, pushbutton switches, and buzzers or bells.

3. Cease-Firing Signal. The order to cease fire is normally given by sounding a special signal consisting of a loud, low-pitched, penetrating buzz produced by an electrically driven device, in addition to transmitting the order in words. This signal is usually transmitted co independent reproducers at the mounts or tu rets. In certain machinegun systems this circu can be so interconnected with the headsets o gun crews' telephones that they will hear th cease-fire signals in their phones as well a over the reproducers installed at the mount.

4. Salvo Signals. The salvo signal is variable-pitch buzz produced electrically b special apparatus. Salvo-signal reproducers a installed where they can be heard by the cr in the gun compartments. There is no salvo signal circuit for the machinegun battery.

ALARMS

The IC system includes a number of alarm for use in alerting or signaling personnel wi regard to a specific dangerous condition. Th number and type of alarms vary with type o ship. Four main alarms are:

1. Collision alarm
2. Chemical attack alarm
3. General alarm
4. Sonar alarm

The above listed alarms are connected into t ship's 1MC circuits. The closure of an aler contact maker anywhere in the ship will sou any one of the four alarm signals over all ci cuit 1MC loudspeakers. The alarms are list

in the order of their priority which is automatically controlled by relays in the audio amplifier. Any alarm takes priority over voice announcements.

If an alarm is being sounded and a higher priority alarm contact maker is closed, relays operate to cut off the alarm signal being sounded and cause the higher priority alarm to be sounded instead. Conversely, the closure to a low priority alarm contact maker has no effect on a high priority alarm that is being sounded. The system operates to generate the alarm signals as long as the alarm contact maker is held closed (except for general alarm which is sounded for a predetermined 15-second interval after momentary closure of the general alarm contact maker).

A few independent alarm systems used on board ship are:

1. Emergency steering alarm
2. Fire alarm
3. Carbon dioxide (CO_2) alarm

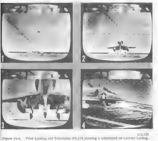


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Figure 14-4. - Pilot Landing Aid Television (PLAT) showing a videotaped jet carrier landing.

CLOSED-CIRCUIT TELEVISION

One of the most prevalent Navy uses of closed-circuit television (TV via cable) is data display. Instantaneous and accurate data are sent by a TV camera mounted in CIC to receivers in weapons control, commanding officer's tactical plot, flag plot, and the air control section of CIC via a high resolution, closed-circuit television system. The addition of television equipment has done much to eliminate the time-consuming link formerly associated with the transfer of bogey data by sound-powered telephones. Telephones are still used for action commands and to provide an audio backup for visual information. They continue to be the information link to antiair warfare stations that do not have a critical evaluation assignment.

Pilot Landing Aid Television (PLAT) has been installed aboard almost all U.S. Navy aircraft carriers. This closed-circuit tele-vision system aids in landing aircraft, and records landings on videotape for immediate playback and analysis by pilots. Figure 14 shows a sequence of photographs taken from a shipboard television monitor displaying a jet carrier landing. A television camera mounted in the center line of the carrier deck spots the plane at the beginning of its landing approach, and follows it to the touchdown. A second TV camera on the carrier's superstructure then takes over. Crosshairs on the monitor assist the landing signal officer in talking the pilot down to a safe landing. Minute-by-minute records of time, air speed, wind velocity, and flight number are shown on the dials at the top of the screen. Audio recordings of the conversations between the pilot and the landing signal officer are made on the same tape along with the video information. The tape is a complete record of each landing, day and night.

CHAPTER 15

THE JUNIOR WEAPONS OFFICER

This chapter is not so much the finale to this textbook on "conventional" naval weapons as it is an introduction to the first stage of your probable career in the weapons department of a U.S. Navy ship, regardless of what armament it carries. It introduces to you some of the practical day-to-day details that fill a naval officer's life on board ship. This chapter is principally focused on what you as a junior officer in the weapons department can expect to experience.

In the remainder of this chapter, assume in all cases that we are discussing a surface combatant ship other than an aircraft carrier. Where there's a choice between a large ship and a small one, assume a small one like a destroyer or destroyer escort. (Exceptions will be indicated or apparent from context.)

KNOW YOUR SHIP

Aboard many ships, one of the first things the commanding officer might tell a new officer to do is perform some orientation assignment like locate and map on a large sheet of paper all the watertight doors on the ship or trace certain communication lines. Some commanding officers put new officers through a fairly detailed and time-consuming "geographical" orientation course of this kind. This is not arbitrary. If your CO doesn't tell you to do it when you report aboard, you should do it on your own. You should get to know the ship's layout and characteristics even better than you knew the dwelling you lived in ashore—unless you traced all the plumbing and utility lines at home. This information isn't hard to find. It's in the ship's damage control and general information books, which are available from your department head or the Engineer Officer. You should learn the ship's organization and procedures just as soon as you are able. (You can get these from the ship's organization manual, from the ship's general information book, from NWP 50, and from other sources that the executive officer or your department head can provide if you ask for them.) Get the ship's tactical data folder and the appropriate NWPs to find what your type of ship, and your particular ship, can and is expected to do.

KNOW YOUR DEPARTMENT

Don't forget the department of which you're a member. Get to know the watch, quarter, and station bill, and the relevant parts of the ship's organization manual on which it's based. If you're assigned to a division in the weapons department, get to know just what material your division is responsible for, and study the Current Ships Maintenance Project (CSMP) file and other ordnance files—and read the log books too—so that you will at least have some acquaintance with the armament aboard. Find out also about the training program—how it works, what records are being kept, the training policies of the weapons officer, the commanding officer, and the executive officer.

There is much more to be said on the points of self-study, initiative, and inspiration than there is space for here. Remember especially that to do your job, you need self-training; for this you need initiative; and if you have initiative, it will seldom be necessary for your superiors to tell you what to do, because you'll know it, and do it.

THE JUNIOR OFFICER

Soon after you report aboard ship the commanding officer will assign you a billet (a job title). If you are assigned to the weapons department, your billet could be anything from a junior division officer to assistant weapons officer. You would most likely be assigned as

a departmental assistant, such as fire control officer. (Other assistants are listed in a later section.) There is a good chance you will be a division officer as well, depending on the number of officers in the weapons department and the organization of the department. (The division officer's responsibilities and the practical aspects of his duties are discussed later.)

By understanding the weapons officer's duties and responsibilities you will better understand your own. Your specific duties may be a portion of the weapons officer's duties or, as assistant weapons officer, you would be involved with nearly all the duties of the weapons officer. In any case you need to understand them eventually so you will be prepared to become the weapons officer yourself some day.

THE WEAPONS OFFICER'S RESPONSIBILITIES

The weapons officer directs activities of the weapons department; advises and assists the commanding officer on weapons operations and problems; directs operation, maintenance, and repairs of all weapons and weapons direction and control equipment; supervises care, handling, stowage, and use of explosives; interprets and applies ordnance regulations and directives issued by technical bureaus and higher command; establishes a weapons department training program, organizing department drills and exercises; ensures performance of deck seamanship operations such as anchoring, mooring, fueling at sea, cargo loading, and care and maintenance of equipment connected therewith; and inspects spaces assigned, including exterior surfaces of the ship, to ensure proper care and maintenance. The weapons officer's responsibilities are also discussed in general terms in chapter 1. In chapter 9 they are discussed with regard to spotting and shore bombardment, and in chapter 14, they are discussed in connection with battle organization.

ORGANIZATIONAL RELATIONSHIP OF THE WEAPONS OFFICER

The weapons officer reports to the commanding officer for the employment and readiness of system (except on ASW aircraft carriers) and deck seamanship equipment. These are operational responsibilities. The weapons officer is responsible to the executive officer for administrative matters.

Now, how about those directly responsible to the weapons officer? You already know that on most ships the fire control officer is not the only officer assistant that the weapons officer has. The weapons officer can have any or all of the following assistants, depending on the type of ship and its organization:

1. Assistant weapons officer
2. Gunnery assistant
3. First lieutenant
4. Gun battery officer
5. AA control officer
6. Fire control officer
7. Missile officer
8. CO of Marine Corps detachment
9. ASW officer
10. Nuclear weapons officer
11. Warrant officers
    a. Fire control gunner
    b. Ordnance gunner
    c. Missile ordnance gunner
    d. Missile test and repair officer
12. Division officers

The functions of some of the primary departmental assistants mentioned above are described at length in the following articles. The names give you an indication of their areas of responsibility. Under them are the division officers (though on smaller ships or where the allowance is limited some of the departmental assistants may double as division officers). One of the departmental assistants usually functions as assistant weapons officer when necessary. He has much the same relationship to the weapons officer as the executive officer has to the ship's commanding officer.

FIRST LIEUTENANT

The first lieutenant supervises and directs the deck force in performance of seamanship functions and evolutions; gives direct commands or delegates responsibility for immediate supervision to the ship's boatswain or petty officers during various evolutions such as mooring, docking, anchoring, fueling, or transferring personnel and cargo at sea; assigns boats and boat crews in compliance with ship's boat schedule; supervises readiness of boats and survival equipment by frequent inspection, and orders repairs or replacements as required (with the

exception of power boat engines and engine compartments, which are the responsibility of the engineering department; directs preservation of weather decks, ship's exterior, running gear, ground tackle, and boson's stores; arranges for the training of deck divisions, scheduling drills and classes in deck seamanship, boat handling, and marlinespike seamanship; recommends transfer, reassignment, and promotion of deck personnel; directs the preparation of weekly, monthly, and quarterly reports as required; and maintains files and records for reference by deck divisions.

FIRE CONTROL OFFICER

The fire control officer directs the division of the weapons department concerned with operation, maintenance, and repair of weapons and guided missile weapons control equipment and systems; assigns personnel to operation and maintenance duties on all weapons control equipment and systems; establishes and supervises training programs, scheduling classes and drills; supervises division personnel, administering liberty, leave, and transfer; and approves assignment of weapons control personnel to the watch, quarter, and station bill.

MISSILE OFFICER

The missile officer directs the operation, maintenance, and repair of guided missile installations and associated equipment; establishes and supervises a training program for guided missile personnel, scheduling drills and organizing firing practices; ensures compliance with maintenance and repair instructions; inspects missiles and missile battery, and supervises major repair tasks and alterations; directs operation and maintenance of guided missile launchers, loading systems, and loading/launching control systems; directs assembly, tests, and maintenance of guided missiles and components; interprets current directives from technical bureaus and higher commands concerning guided missile battery doctrine and regulations; and supervises preparation of the required records and reports.

ASW OFFICER

The ASW officer directs employment, operation, and maintenance of all antisubmarine equipment in the weapons department; assists the commanding officer during antisubmarine search and attack; directs the operation, care, and maintenance of all antisubmarine equipment, including search and attack sonar, fire control equipment, weapons, attack aids, torpedo countermeasures, and underwater communications equipment used in identification and classification of submarines; supervises and trains personnel assigned to the department or to antisubmarine stations in sonar search techniques, submarine contact evaluation, operation of equipment, and antisubmarine doctrine; and advises superior officers on all matters concerning antisubmarine operations.

NUCLEAR WEAPONS OFFICER

The nuclear weapons officer plans and executes maintenance and repair of nuclear weapons, components, and testing and handling equipment assigned; directs and coordinates functions of the nuclear weapons division; directs overall functions of assembly teams; ensures that prescribed quantity and quality of nuclear weapons are maintained; directs a training program within the division; ensures that adequate safety and security measures are carried out; and supervises maintenance of records and preparation of reports required.

THE DIVISION OFFICER'S GENERAL RESPONSIBILITIES

In general terms, the division officer is responsible for carrying out the policies of the commanding officer as amplified by the executive officer and department head. He is responsible under the head of department for the organization, administration, and operations of his division. The division officer reports to the head of department for the performance of his assigned duties. All personnel in his division report to him; if junior division officers are assigned they also report directly to him.

SPECIFIC AREAS OF RESPONSIBILITY

In more specific terms, the division officer's responsibilities can be divided into six main categories:

1. Organizational responsibilities
2. General administration

3. Personnel administration
4. Material responsibilities
5. Training
6. Miscellaneous

In the next three sections we'll discuss practical aspects of these responsibilities.

ORGANIZATION, ADMINISTRATION, AND MISCELLANEOUS

From the six areas of division officer responsibility mentioned in the preceding section, we'll attempt to concentrate on those aspects that specifically involve the weapons department and the ship's armament. This text is primarily concerned with these aspects rather than with those that apply to all departments and officers in general. If we do this, it becomes clear that of the six, the two areas that are most peculiar to the weapons department and the ship's armament are material and training. These two are therefore taken up in detail in the next two sections. In the present section, we discuss, rather more briefly, the four areas which, though important, are also of more general application in all departments, not merely the weapons department. These are: organization, administration, personnel, and miscellaneous responsibilities of the division officer. So far as possible we'll concentrate on the aspects of these areas that are specifically applicable to the weapons department.

DIVISION ORGANIZATION

Figure 15-1 illustrates schematically the organization of a representative fire control division aboard a destroyer (DD).

Many of the elements of this organizational scheme you have seen before. You already know that under the department head are the division officers. The division officer will generally be an ENS or a junior LTJG. If he has a junior division officer it will most likely be a junior ENS. On a large combatant ship (such as a cruiser or aircraft carrier) the division officer will generally be a LT or LTJG assisted by a junior division officer with a rank of ENS or possibly LTJG plus one or two warrant gunners to assist with technical problems of fire control and weapons operation and maintenance.

The leading petty officer in the division is usually a Chief Gunner's Mate, but he may be a Chief Fire Control Technician. The remainder of the division consists of three watch sections, each under a section leader. Section leaders function as military superiors as well as technical supervisors.

During peacetime, personnel on board are frequently lower in rate than the allowed billets call for. Where the divisional organization chart calls for a chief petty officer, quite often you will find a Petty Officer First Class in the slot. The same holds true all the way down the line. A Petty Officer Second Class often fills the billet of a First Class. Very often you will find strikers performing the duties of a Petty Officer Third Class.

In figure 15-1 the second section is broken down in detail; the other two sections are set up similarly, except that the distribution of rates and ratings is not identical. At times there are not enough crewmen aboard to fill all the allowed billets. Depending on the personnel on board and their qualifications, a billet may be filled by a man with a lower rate or a related but different rating. For example, a Gunner's Mate Second Class may fill a Gunners Mate First billet or a Fire Control Technician's billet.

ST1 stands for Sonar Technician 1st Class. Sonar Technician is a rating — the designation of a specific group of specialist. First Class is a rate, corresponding to a pay grade. (The distinction is worth remembering.) The ST1 may supervise a Sonar Technician Striker — a non-petty officer who is in training for ST 3 or ST S Third Class.

The organizational arrangement of personnel, which is taken from the ship's organization manual and shown on the watch, quarter, and station bill, is used for administrative purposes, including the assignment of personnel to cleaning stations (as shown in figure 15-1). Personnel are withdrawn temporarily from their cleaning stations for specific evolutions covered by ship's bills, which we will discuss next.

SHIP'S BILLS

A ship's bill is the method of establishing assignments of ship's personnel to duties and stations for the purpose of executing specific evolutions or accomplishing certain functions. In general, a bill includes the following information:

1. Statement of purpose
2. General information
3. Assignment of responsibilities

110.122

Figure 15-1.—Representative organization of F division aboard a destroyer.

4. Statement of organization
5. Assignment of personnel
6. Procedures

Bills are classified as:

1. Administrative
2. Operational
3. Emergency

Since all officers must be familiar with the ship's organization manual, they must be acquainted with all the ship's bills, even those for which they have no direct responsibility. Table 15-1 gives a partial list of the bills used on a typical destroyer along with the title, purpose, and organizational designation of the officer responsible for preparing it.

SHIP'S PROCEDURES

Like bills, the term procedures also has a special meaning in this context. A procedure is a written statement of a series of coordinated steps by an organizational unit for the accomplishment of a specific function. Shipboard procedures are classified under one of the following categories:

1. Personnel
2. Accountability
3. Operating

Personnel procedures include such matters as disciplinary measure, leave and liberty, petty officer evaluation, training, how to deal with visitors, the handling of U. S. mail, etc. Accounting procedures cover such matters as

Table 15-1.—Summary of Ship's Organizational Bills

BILL	PURPOSE	RESPONSIBILITY
	To establish procedures and assign duties for:	
Personnel Assignment Bill	Assignment or reassignment of officers and enlisted men to billets within departments and divisions of the ship.	Executive Officer.
Berthing and Locker Bill	Assigning berthing and locker facilities.	Executive Officer.
Cleaning and Maintenance Bill	Maintenance, preservation and cleanliness of the exterior and interior of the hull, hull fitting, machinery, and equipment.	Executive Officer.
Special Sea Detail Bill	Getting underway and returning to port.	Navigator.
Replenishment at Sea Bill	Fueling, rearming, provisioning, or transferring personnel at sea.	First Lieutenant.
Rescue and Assistance Bill	Rendering emergency assistance to persons or activities outside the ship.	Engineer Officer.
Landing Party Bill	Conducting limited field operations, policing during an emergency, and participating in parades and ceremonies.	Weapons Officer.
Visit and Search, Prize Crew, and Boarding and Capture Bill	Investigating, salvaging, and taking possession of another ship.	Operations Officer.
Towing Bill	Towing or being towed by another ship.	First Lieutenant.
General Emergency Bill	Controlling the effects of a major emergency or disaster suffered by the ship, such as collision, grounding, internal or external explosion, nuclear contamination, earthquake, storm or battle damage.	Engineer Officer.
Man Overboard Bill	Recovering one man or a small number of men from the water.	First Lieutenant.
Nuclear, Biological, and Chemical (NBC) Defense Bill	Provide an organization, prescribe procedures, and assign responsibilities for proper and effective action when involved in NBC warfare or in NBC weapon accident situations.	Engineer Officer.

110.165

material inventories and surveys, and accounting for mess, welfare, and recreation funds. Most of these are set forth in chapter 9 of NWP 50(A), Navy manuals on correspondence and filing, and OPNAV and SECNAV instructions.

Table 15-2 is a partial list (with references) of representative operating procedures aboard a destroyer.

MISCELLANEOUS (COLLATERAL) DUTIES

Besides the assigned departmental duties and the regular military duties of the division officer (such as underway watches, in-port watches, and GQ assignments), all officers are assigned collateral duties (secondary duties). These include serving on committees and boards (such as the audit board, the recreation committee, courts-martial boards, and officer candidate examining boards) and performing some special function such as intelligence officer, photographic officer, classified material control officer, or legal officer.

On a destroyer a division officer might expect on the average to have two or three such collateral assignments. On ships with more personnel, like cruisers and carriers, some of these duties (such as legal officer or education officer) may be assigned as primary duties.

MATERIAL

As a junior officer assigned to the weapons department, much of your daily activity will be concerned with the material readiness of your division. The complexity of modern naval weapons requires a program of constant testing and maintenance to ensure system operability. The Navy's material management program is centered about the Navy Maintenance and Material Management (3-M) System. The 3-M System, a relatively new maintenance program, can be

Table 15-2.—Shipboard operating procedures

TITLE	REFERENCES OTHER THAN FLEET AND TYPE DIRECTIVES
Jettison procedures	Chapter 9, NWP 50(A)
Strip ship procedures	Chapter 9, NWP 50(A)
Scuttling the ship	Chapter 9, NWP 50(A)
Emergency destruction of classified matter	Chapter 9, NWP 50(A)
Steering casualties	Chapter 9, NWP 50(A)
Operations with helicopters.	NWIP 41-6
Fog navigation.	Chapter 9, NWP 50(A)
Darken ship procedure	
Security against sneak attack procedure	
Repel boarders procedure	
Dry docking procedures.	(a) BuShips Manual Chapter 7 (b) USNR 1948 Articles 0749, -790, 0791, and 2030
Mediterranean moor procedure.	
Small boating procedure	

110.164

a source of difficulty for those who do not understand its function and operation. Several books that explain the intricate details of the system are available. However, because of its importance in the management of the shipboard ordnance organization, let us take a look at the 3-M System to see how it relates to a junior officer in the weapons department and review some of the documentation used in weapon maintenance.

ADMINISTERING THE MAINTENANCE PROGRAM

By definition the 3-M System is "a shipboard management system which, when fully implemented and properly used, provides for (1) orderly scheduling and accomplishment of maintenance, and (2) reporting and disseminating of maintenance-related information." Simply stated, the system is a tool with which maintenance personnel manage their resources. What are resources? As a maintenance manager you have three resources—men, material, and time. Any maintenance action will require the use of all three. You must have the material on which, or with which, to perform the maintenance, and you must have men with a given amount of time to do the job.

Planned Maintenance Subsystem

To be an effective manager, you will need some means of planning, scheduling, and managing the use of your resources. This idea of scheduled maintenance is not new. A look at the plan of the day from one of our revolutionary war frigates would show a time set aside for "exercising the crew at quarters" (general quarters drill). It was during these drills that the guns were checked to ensure they would fire if needed.

This action is called planned preventive maintenance, a maintenance action performed to locate potential trouble spots, and is the Planned Maintenance Subsystem (PMS) portion of the 3-M System. This type of maintenance reveals troubles while they are small and easily corrected, before they develop into major casualties. The PMS provides for three actions: planning, scheduling, and management. PMS material, such as work schedules, maintenance cards, and other maintenance documentation, provides Navy-wide maintenance standards based on engineering experience and prescribes procedures and techniques for accomplishment of maintenance. The tools of the PMS are discussed in detail in OPNAV publication 43P2.

Maintenance Data Collection Subsystem

If you managed a civilian business, you would need records to document the usage of your resources. These records would provide you with information to use in improving your business operation. The operation of your Navy requires a tremendous "maintenance business." To analyze how our three resources are spent—and thereby improve the operation of our naval arsenal—we must have records that will indicate the performance of our equipment and the use of men, material, and time. This record is achieved with the second portion of the 3-M System called the Maintenance Data Collection Subsystem (MDCS). The MDCS provides a means of recording the expenditure of our resources associated with minor corrective maintenance, major repairs, and authorized alterations to equipment. It also provides a method for processing maintenance action and logistic information and disseminating this data for use by activities concerned with the management of naval material.

HISTORY OF MAINTENANCE PROGRAM

Operation of the 3-M System as related to weapons can be better understood by examining the different maintenance documentation associated with weapons and by reviewing the history of the system's development.

Little maintenance documentation was needed with the preventive maintenance system used in the days of the sail. Weapons were simple and parts used for repairs were obtained from the local economy. As more complex weapons came into use, better documentation was required. The Bureau of Ordnance (forerunner of the Naval Ordnance Systems Command) began to develop and publish ordnance pamphlets (OP's) which described the operation of various weapons. The books became known as OP's and were eventually assigned numbers which identified the OP to a particular weapon or

subject. Ordnance data sheets (OD's) also were issued, giving some of the specifications, and engineering data of different equipments.

Ordnance Pamphlets

OP's written prior to the 1950's contained very little information concerning preventive maintenance. These books usually had three major sections: (1) Introduction, (2) Theory of operation, and (3) Maintenance. One of the OP's from this period concerned the 8-inch, Triple-Gun Turret. In the electrical system maintenance section the only preventive maintenance described was a periodic check of the wiring for looseness, moisture, and chaffing. This was not much, considering the amount of electrical machinery in an 8-inch turret. No schedule was given as to when this maintenance should be accomplished. As weapons became more complex, OP's and OD's were improved. The OP's that were published in the 1940's contained checklists to be followed when preventive maintenance was performed.

Ships Maintenance Program

The Navy began to document and record maintenance actions during this period and a maintenance program called the Current Ships Maintenance Program (CSMP) was brought into operation. The CSMP did not describe how or when a maintenance action was to be accomplished. As maintenance supervisors determined that a maintenance action was necessary, entries were made to that effect on a card and were filed in a loose leaf binder. When the action was accomplished, the card was removed and destroyed after the maintenance action was recorded on the permanent CSMP record (ordnance history cards for weapons equipment). This system lacked good scheduling and allowed for little planning ahead, except for major repairs and overhaul. Routine day to day maintenance was accomplished in whatever manner the petty officer in charge of the equipment thought best.

Satterwhite System

Different bureaus of the Navy Department tried different maintenance programs. One, instituted by the Bureau of Ordnance, was developed by a Chief Fire Controlman named Satterwhite. This system, known as the Satterwhite System of Maintenance, was designed to ensure that adequate preventive maintenance was accomplished daily, weekly, monthly, or as often as necessary on the Mk 56 Gun Fire Control System. Complete, easy to understand instructions were provided for each step of the maintenance action along with a list of tools and the number of men required. The Satterwhite system also provided for recording the maintenance performed, but only at the local level. CSMP cards were still used for permanent records.

Integrated Maintenance Plan

Along with the different maintenance programs adopted by the various Bureaus, Fleet Commanders published some maintenance instructions. Since these were published at the fleet level, several different maintenance programs could be found in effect on the same type of equipment. In the early 1960's the complexity of the Navy's surface missile systems required that a standard maintenance plan be put into effect for all fleets. The Bureau of Naval Weapons (another forerunner of the Naval Ordnance Systems Command) attempted to standardize the maintenance of all surface missile systems by issuing the Integrated Maintenance Plan (IMP).

The IMP was to achieve better operability through better maintenance documentation. Complete testing procedures, engineering information, and troubleshooting techniques (along with a scheduled preventive maintenance routine) were made a part of the IMP documents. Special OP's were published with more emphasis placed on maintenance and less on theory of operation. In addition to the standard OP number, these documents also carried the letters "IMP" to identify them as Integrated Maintenance Plan documents.

One of the most significant advantages introduced by IMP was the establishment of Daily Systems Operability Tests (DSOT). Prior to IMP, individual units of a weapon system were checked daily for proper operation (e.g., computer, radar, director, and gun), but dynamic operation of the entire system was not usually monitored. DSOT checks overall material readiness by monitoring the operation of all equipments of the system functioning as an integrated unit. The DSOT method of checking system performance has been incorporated in the 3-M system.

THE 3-M SYSTEM

Weapons department personnel were not the only ones having maintenance problems. All departments having maintenance-related responsibilities were finding maintenance of the new ships of the 1960's more complex. A Navy-wide system of planned maintenance and maintenance documentation was needed. In the mid-1960's the Chief of Naval Operations placed into effect the 3-M System, to be used by all departments, aboard all ships, in every fleet.

The 3-M System is intended to assist Navy operational and technical commanders (and division officers) in attaining and maintaining optimum fleet readiness through the efficient and effective use of available resources. Specific objectives of the system are to:

1. Define and achieve uniform maintenance standards, criteria, and procedures.
2. Assist operating forces (a) by promoting effective utilization of available manpower, material, and maintenance opportunities and (b) by reducing the total administrative burden on maintenance personnel.
3. Document the requirements for and the accomplishment of maintenance and the utilization of maintenance resources.
4. Increase knowledge of current ship's configuration and identify desirable changes to existing configuration or improvements in new ships design through information gained by documentation of maintenance actions.
5. Improve maintainability and reliability of equipments.
6. Accurately identify the cost of maintenance in terms of manpower, material, and funds, and minimize these cost through management effectiveness.

With the innovation of the 3-M System, OP's are being revised to conform to 3-M requirements. Most of the OP's associated with surface missile systems have been revised and are now labled PMS/SMS (Planned Maintenance System/Surface Missile System). Some IMP publications are still available but most have either been included in or superseded by PMS/SMS documents. OP's for some gun systems are being revised to conform to 3-M requirements. Special subject OP's (such as safety precautions, ammunition handling, and other nonmaintenance subjects) are unaffected by 3-M. The Index to Ordnance Publications, OP O, contains a listing of all OPs and ODs showing current status (superseded, canceled, PMS/SMS, etc.) and availability. Any of the publications we have mentioned can be used as an aid in meeting PMS requirements. Where there is a difference between stated requirements of the PMS and other technical publications (OP's), the PMS requirements prevail.

The 3-M System is not a cure all for maintenance and does not diminish the need for good management and leadership. Neither is it a passive system. It cannot succeed without active, aggressive supervision at all levels, from operational commander to the work center supervisor. As division officer (or junior division officer) you must take the initiative and ensure that all requirements of the 3-M System are met.

Maintenance Organization

In order to derive maximum benefit from the 3-M System, the aggressive type of positive leadership must be built into the ships organization. While there is no single master plan which will ensure optimum effectiveness in all classes of ships, there are certain organizational concepts and responsibilities which must be adopted by every ship in which the 3-M System is installed. Let's review these basic responsibilities as outlined in OPNAV 43P2.

COMMANDING OFFICER.—The Commanding Officer is responsible for ensuring that ship's maintenance is accomplished in accordance with the procedures of the 3-M System, and that the system functions effectively within his command. He will make certain that all appropriate personnel receive adequate 3-M training and meet with the Executive Officer, 3-M Coordinator, and other maintenance managers to review the status of material readiness, discuss 3-M matters, and provide necessary guidance and coordination.

EXECUTIVE OFFICER.—The Executive Officer is responsible to the Commanding Officer for the overall organization and operation of the ship's 3-M program. He provides the overall supervision and coordination required to ensure system effectiveness. To accomplish these goals he acts as chairman for periodic 3-M meetings with department heads and the 3-M coordinator to review and monitor 3-M operation. He drafts ships directives concerned with 3-M and ensures that all departments comply with these instructions. In addition, he

coordinates incorporation of 3-M training into the ship's training program and establishes an effective program for assigning job control numbers and for filing MDCS information.

THE 3-M COORDINATOR.—The 3-M coordinator is responsible to the Executive Officer for coordination and direct supervision of all facets of the ship's 3-M program. Where personnel resources permit, this will be the primary duty of an officer or senior petty officer who has had formal training in 3-M. The 3-M Coordinator works with the various department heads and department 3-M assistants to ensure that the effectiveness of the ship's 3-M program is maintained.

DEPARTMENT HEAD AND DEPARTMENTAL 3-M ASSISTANT.—Each department head is responsible for the effective operation of the 3-M System within his department. As an aid to managing his 3-M responsibilities, the department head will assign an officer or competent petty officer the duty of departmental assistant. Both should be formally trained in 3-M. Unless otherwise directed by Fleet or Type Commander, the department head must personally supervise all cycle and quarterly scheduling of departmental maintenance and ensure proper supervision of other departmental 3-M functions, as follows:

1. Regularly inspect the 3-M operation within the department, including weekly review of the departmental maintenance control board.

2. Emphasize to the personnel of his department the importance of properly scheduled maintenance and the proper documentation of the maintenance performed.

3. Ensure departmental personnel are properly trained and motivated concerning the 3-M System, and that departmental 3-M training records, files, and publications are properly maintained.

4. Conduct periodic meetings with division officers and work center supervisors to ensure continuing knowledge and necessary coordination, in 3-M matters.

5. Assist division officers and work center supervisors as necessary in obtaining 3-M supplies and scheduling weekly maintenance.

6. Personally sign cycle and quarterly schedules prior to posting.

SUPPLY OFFICER.—The supply officer will coordinate the efforts of his department to best support the ship's maintenance effort.

DIVISION OFFICER.—The division officer is responsible to the department head and should be formally trained in the 3-M System. He will assist the department head in scheduling maintenance required for the equipment under his cognizance as follows:

1. Ensure, by daily inspections, that weekly schedules are in accordance with the departmental quarterly schedule and the required maintenance is being properly performed and reported

2. Incorporate 3-M training into the divisional training plan and maintain up to date 3-M training records for his division

3. Ensure that MDCS documents generated within his division are complete, accurate, and promptly submitted

4. Assist the 3-M Coordinator as necessary in all matters concerning 3-M within his division

5. Conduct periodic meetings with all divisional work center supervisors and keep the department head informed of the status of 3-M within the division

WORK CENTER SUPERVISOR.—The Work Center Supervisor is responsible to the division officer for the effective operation of the 3-M System within his work center. He shall have received formal 3-M training, and his duties shall include the following:

1. Personally schedule weekly work center maintenance and supervise its proper accomplishment

2. Ensure status-of-work center maintenance is correctly reflected on the departmental maintenance control board

3. Ensure division officer or department head is advised concerning inability to complete scheduled maintenance, and any other problems in 3-M operation

4. Maintain an adequate supply of 3-M materials within the work center

5. Ensure that all required MDCS documents from his work center are correct and promptly submitted

6. Ensure maximum use of the 3-M System as a training aid within the work center, and ensure that such training is properly reflected in the training records

7. Maintain control and accountability of JSNs (Job Sequence Number) within the work center

MAINTENANCE PERSONNEL.—Maintenance personnel are directly responsible to the work center supervisor. Their duties include (but are not limited to):

1. Reading the weekly schedule and performing PMS actions as scheduled each day
2. Being knowledgeable in the procedures for filling out maintenance action documents
3. Informing work center supervisor of completed PMS actions and any problems encountered in performing them

In order to perform your duties related to 3-M you must work closely with the department head and work center supervisor and assist them as necessary in scheduling the work of your division. Let's discuss some of the 3-M items you should become familiar with in order to carry out these duties.

3-M TOOLS

The Planned Maintenance System Manual is a publication used primarily by the department head in planning and scheduling maintenance for his department. A table of contents for each maintenance group within the department is included along with a page for each system, subsystem, or component within the maintenance group. Also, the manual contains a brief description of the maintenance requirements and the frequency with which maintenance is to be effected for all components and equipment. The frequency code is: D-daily, W-weekly, M-monthly, Q-quarterly, S-semiannually, A-anually, C-overhaul cycle, R-situation requirement. The manual contains index pages (group maintenance manual) for each maintenance group within the department—engineroom, fireroom, electrical, and auxiliary. Manuals are compiled individually for each ship, thereby assuring a tailored system.

CYCLE SCHEDULE.—The cycle schedule is a visual display of preventive maintenance requirements based on an overhaul cycle. All the maintenance items listed in the cycle schedule are within the capabilities of ship's force for onboard equipment.

The cycle schedule contains a list of components for each maintenance group. It schedules the semiannual, annual, and overhaul cycle maintenance requirements based on quarters after overhaul. The cycle schedule also lists the quarterly and monthly requirements that must be schedule each quarter. The department head uses the cycle schedule in making out the long-range or quarterly schedule.

QUARTERLY SCHEDULE.—The quarterly schedule is a visual display consisting of two identical quarterly schedule forms. One is for current quarter; the other is known as the subsequent quarterly schedule. The cycle schedual and both quarterly schedule forms are contained in the same visual display holder and correspond, line for line. The entire display is called the maintenance control board. The control board shows the overall preventive maintenance program for the department. The control board usually is located outside the department head's office.

WEEKLY SCHEDULE.—The weekly schedule is another visual display for use in connection with the PMS. It is posted in each maintenance group's work area, along with a copy of applicable pages from the PMS manual. For example, a weekly schedule that applies to maintenance of equipment in a certain area is posted in that area's fire control radar room.

The weekly schedule assigns specific personnel, by name, to perform specified maintenance tasks on particular components on a definite date. Listed on the weekly schedule are the components that are the responsibility of a particular maintenance group. The weekly schedule is used by the supervisor of the working area to assign work and to record the completion of work.

MAINTENANCE REQUIREMENT CARD.—The maintenance requirement card (MRC) is a card, 5 inches by 8 inches in size, on which the preventive maintenance task is defined in sufficient detail that assigned personnel can perform the task without difficulty. Each maintenance requirement card lists rating and rate level of personnel who should perform that particular task; safety precautions that must be observed; the time, tools, parts, and materials required for the task; and detailed procedures for performing the task.

MDCS DOCUMENTS.—In addition to the various schedules and MRC cards there are certain MDCS documents with which you should be closely acquainted. These include: requests for material, manhour accounting documents, work supplement cards, and maintenance data forms. The exact use of these documents will vary from ship to

ship. All are described in the Maintenance and Material Management Manual, OPNAV 43P2.

Perhaps the most important of these MDCS documents is the Maintenance Data Form. This is a multipurpose form used to report maintenance-related actions. Basically, it can be used for three purposes:

1. To report routine maintenance action by work center personnel

2. To report maintenance that has been deferred for various reasons, such as lack of parts or need for outside assistance

3. To request the assistance of a tender, shipyard, or other activity

When used to report maintenance accomplished by work center personnel, the Maintenance Data Form is submitted to the ship's Maintenance Data Collection Center (usually maintained by the 3-M coordinator or engineer officer). This form will then be used to submit a composite ship's maintenance report to a Navywide Maintenance Data Collection Center (MDCC).

If a maintenance action must be deferred for some reason, the Maintenance Data Form is submitted in a manner similar to the completed action just described. One portion of the form is retained on board for subsequent documentation of additional data, while another portion is forwarded to the Navy MDCC. When the defined maintenance is finally completed, or is canceled, work center personnel inform the ship's MDCC which will forward appropriate forms to the Navy MDCC.

The Maintenance Data Form can also be used as a work request. The work request is primarily intended for requesting assistance in accomplishing maintenance actions; but it is also used to request services or assistance not directly related to maintenance, such as diving and utility services. After the work request has been screened by the division officer and department head, it is submitted to the ship's MDCC for inclusion in the ship's work package. High priority work requests will receive immediate attention, but a major portion of the work requests are held for a regularly scheduled yard (shipyard) or tender (repair ship) availability.

Most commanding officers and most weapons officers take pride in how much work the ship's force can do without formal aid from tender or shipyard. The more maintenance work the ship's force can do (and this includes repairs and alterations as well as upkeep), the better condition the ship and its equipment will be in, the better the crew will know the ship and its equipment, and the lower will be the cost. But there are things that the crew cannot do while a ship is in active operation at sea; so periodically, every ship has a yard or tender availability period.

YARD AND TENDER AVAILABILITY PERIODS.—Yard and tender availabilities are not an every-Monday-and-Thursday affair. Attack carriers, for example, ordinarily will run about two years between overhauls. This means that every big repair and alteration job MUST be taken care of during the availability period. (It is well to note at this point the difference between a repair and an alteration. A repair is work necessary to restore a ship or article to serviceable condition without change in design, materials, number, location, or relationship of the component parts; an alteration is any change in the hull, machinery, equipment, or fittings which involves a change in design, materials, number, location, or relationship of component parts of an assembly regardless of whether it is undertaken separately from, incidental to, or in conjunction with repairs.) Shipyards and tenders are busy places and always have plenty of work. Once the availability period is over, the ship cannot come back a day or two later because some job wasn't completed or was overlooked in the hubbub. Thus, a good deal of careful preparation is necessary well in advance. One part of this preparation is inspection by the Navy's highest inspection authority—the Board of Inspection and Survey. This Board conducts acceptance inspections and trials of new ships. It also inspects active ships every three years to determine the state of their maintenance, and it recommends any alterations that may be necessary. And there are other inspections, such as the arrival inspection made by yard engineers whenever your ship arrives at a naval shipyard for overhaul.

The main part of preparation rests with the ship's personnel. It begins with compilation of a work list. The work list is made up of work requests. The division officer and leading petty officers draft the requests, and from them a work list is made. Several weeks before the ship arrives at the yard or tender, the commanding officer holds a conference of department heads, and at this conference the weapons officer adds his requests to the list that will be submitted to the yard or tender, via the type commander.

The list includes also the items discovered by the inspections made shortly before the availability period is scheduled to begin.

If possible, shipyard estimators and engineers inspect the ship in a prearrival inspection before the ship enters the yard. When the ship arrives at the yard there are conferences between the department heads and the shipyard representatives to determine just which jobs will be done, and how. Or, if the ship has come some distance, the preoverhaul inspection becomes an arrival inspection that is done while the arrival conferences are going on.

The yard or tender availability period is a time when a great deal of work can be done that is impractical or inadvisable to try to do (except in an emergency) when the ship is fully operational. This doesn't mean getting the tender or yard to do ship's force work. If the weapons officer is one of the many that take justifiable pride in the self-reliance of their crews in such matters, this would not improve your reputation with him. But you can get assistance from yards and tenders on ship's force jobs. Sometimes their maintenance and repair personnel work up special time-saving jigs and tools for specific operations. If you can, it is wise to take advantage of these during the availability period.

In naval shipyards the formal line of contact between the yard and a ship is through the engineer officer of the ship and the ship superintendent assigned by the yard to your ship during the availability period. The weapons department's line of contact to a shop is by way of the weapons officer, the engineer officer, the ship superintendent, and the shopmaster of the shop concerned.

Tenders are also organized into departments, but the setup is different. The weapons officer's contact would be the ordnance repair officer in the tender, and the division heads on the ship have direct contact with the divisions on the tender that they have business with (such as the machine shop, optical shop, fire control shop, and so on). Some tenders also use a ship superintendent similar to the shipyard's.

SHIP ARMAMENT INVENTORY LIST

Another important document concerned with material is the Ship Armament Inventory List (SAIL). The SAIL, which is produced on data-processing equipment, indicates a ship's ordnance inventory and Ordnance Alteration (OrdAlt) status. It lists in sequence the following: all items pertaining to missile launchers, turrets, mounts, rocket launchers, projectors, torpedo tubes, and depth charge release equipment; all items pertaining to fire control equipment, target designation systems, and weapons direction systems; all items pertaining to missile test and telemetering equipment; and all items pertaining to target control systems.

Each ship has two copies of the SAIL. Prior to a scheduled overhaul, one copy should be annotated with OrdAlts that have been completed since the last printing; this copy should be sent to NavOrd about seven months prior to the scheduled availability. The other copy is kept on board. After the availability is completed, the SAIL is annotated to indicate all changes, deletions, additions, and corrections, and a copy is forwarded to NavOrd. Changes made at other times are reported on the SAIL Change Report, NavOrd Form 8000/2.

TRAINING

In any department on board ship no factors affect performance more than the efficiency and spirit of its personnel. The efficiency and spirit of the personnel depend heavily upon training. Training starts at the lowest level, goes right up to the highest, and is never finished. At all levels it must be a continuous, progressive, and challenging process, designed around realistic problems and situations, and intelligently handled to create and maintain interest and enthusiasm.

All this applies as much, if not more, to the weapons department as to any other. One of the duties of the weapons officer is the supervision and direction of the employment of ordnance equipment. It is the junior officer's duty to implement this program by proper training of personnel. There are several requisites for an effective training program. The junior officer must be completely familiar with the ordnance equipment for which he is responsible. This includes not only operating procedures, but theory and design characteristics as well. He must ensure that petty officers and other key personnel, who will conduct instruction at station, are themselves competent and well informed. The junior officer must carefully appraise his men and assign them stations in accordance with their capabilities, both mental

and physical. Some information can be obtained from each man's service record, which is available in the ship's office. The division officer should supplement this with a division notebook—which should contain detailed data on each man in the division—as well as a copy of the division watch, quarter, and station bill.

Finally, the junior officer cannot neglect his own training. He must apply himself continually and learn not only his job but the jobs of those who are immediately senior to him.

THE NAVY'S TRAINING PROGRAMS

The Navy has many training programs. One of them is concerned with your studying this book right now. To the division officer aboard ship, the important programs can be considered in three categories:

1. Team training programs for the ship's personnel

2. Individual training programs for enlisted personnel

3. Individual training programs for commissioned officers

Team training programs are those in which groups participate for group training. There are more varieties of team training programs than can ever be summarized here. They range all the way from fleet maneuvers including thousands of men and scores of ships and aircraft, to loading drill practice in which only three or four men are participating.

Individual training programs may actually involve group study and instruction, but are concerned with teaching the individual.

The Navy's training programs are not confined to schools—even special Navy schools—though the Navy does make use of schools. To get a quick picture of the Navy's training programs, let's trace briefly through the training of an enlisted man, then that of an officer. In reading both of these discussions, bear in mind that we are here particularly concerned with what you may expect to encounter aboard ship in the weapons department. Do not consider these brief summaries as a complete exposition of the whole picture.

CAREER OF AN ENLISTED MAN

Training of an enlisted man starts soon after induction. When he's inducted, he's a Seaman Recruit (SR). This is the bottom of the ladder. He goes to boot camp (more formally known as recruit training school), where he learns the basics of Navy life. In boot camp, the SR is not only trained, but tested and screened. He takes intelligence tests, test of ability to use numbers, mechanical and other aptitude tests, interviews, etc. Then he's evaluated and screened on the basis of these tests, and this to a considerable degree determines his career in the Navy. For example, the scores on his tests determine whether he is eligible to try for certain ratings. Electronics Technician and Fire Control Technician strikers, to specify two such ratings, must have passed their tests with relatively high minimum scores in general intelligence, ability to handle numbers, and mechanical aptitude.

It's at this stage also (if it hasn't been done before) that a recruit is shunted into the particular branch he's interested in and qualified for, such as seaman apprenticeship, construction apprenticeship, or medical apprenticeship, to mention a few. As he rises in any of these fields, he becomes more specialized. Recruits with especially favorable test scores and backgrounds may at this stage be "designated" for even greater specialization. Thus a recruit with experience in precision machinery or electronics, and good intelligence and mechanical aptitude scores may go direct from boot camp to specialized "class A" school from which he graduates as a "designated striker" to be assigned to the weapons department as soon as he reports on board ship.

More frequently, however, the recruit when he emerges from boot camp has been advanced to apprentice (Seaman Apprentice or SA, if he's been assigned in that branch) and is sent to a ship, where he becomes part of the deck force. (On a destroyer, this would be the first or second division.) After several weeks or months of observing him, his division officer and the petty officers immediately over him can fairly accurately appraise his career potentialities, and he can be transferred from the deck force to some group in which his talents and interest can be best employed. After 6 months as an SA he can take a written test, which is given by the ship, to become an SN, assuming he

meets all other requirements. He can become a designated striker as an SA or SN provided he meets all the requirements.

To get the rate he's striking for, the candidate for advancement to petty officer third class must:

1. demonstrate that he can actually perform the practical requirements of the rate as evidenced by the Record of Practical Factors, NavPers 1414/1.
2. successfully complete the required military and professional correspondence courses. If required, the striker must also have attended a service school (more about this later).
3. pass a written servicewide examination on the technical aspects of the rate and rating he's striking for and on the military requirements for the rate.
4. be recommended for promotion by the ship's commanding officer. In effect, this is the equivalent of saying that he must be considered qualified by his supervising petty officers (PO's) and have been recommended by his division officer.
5. have been in grade and in the Navy the required minimum time.

BuPers directives promulgate all these requirements in detail. The list above is only an abbreviated review.

The striker's chances for advancement depend on his examination score (item 3 above) and other factors such as length of service, proficiency marks, and awards, which all together determine his score total. If he has a passing mark, this can qualify him for advancement to petty officer third class for the particular specialty (rating) he's striking for, but he isn't automatically moved up to this rate. Instead, the names of all those who took the examination are arranged in the order of their standing, and those highest in the list are advanced until the Navy's requirements for this particular rate and rating are satisfied.

The advancement of petty officers continues step by step (no skips permitted) in this general pattern through all the grades up to the highest (Master Chief Petty Officer). It is worthwhile for the division officer to remember that many an able man can fully qualify for advancement but not actually be advanced, simply because in his rating there are fewer available billets than qualified candidates for advancement.

Although the top of the enlisted ladder is Master Chief, it is well to note that certain qualified enlisted personnel may enter the officer ranks through programs such as Warrant Officer, NESEP, NROTC, OCS, and the Naval Academy (fig. 15-2).

CAREER OF AN OFFICER

Let's now glance briefly at how an officer rises in the ranks. In contrast to the picture in the preceding article, where in a sense you're outside of the frame of reference, you're right in the middle of this one.

For an officer, the bottom of the ladder is the rank of ensign. Some attain this rank from (as the preceding section pointed out) enlisted or warrant status, by way of OCS (Officer Candidate School). Others are Naval Academy graduates or NROTC or other college officer training graduates.

We won't go into the details of the complex machinery of officer promotion, but you probably know already that an officer is selected (i.e., declared eligible) for promotion before actually being promoted. To ensure himself of actual promotion, a selected officer must be prepared for it. Aside from the obvious matter of knowing his job and doing it so that it will do him credit, he must also train himself systematically, so that he will be ready for promotion when it looms ahead. Here are some aspects of this training preparation.

1. CORRESPONDENCE COURSES. United States Armed Forces Institute (USAFI), Navy,

110.166
Figure 15-2. — Enlisted-to-officer programs.

and other correspondence courses are recommended for all officers to help prepare themselves for advancement and to broaden their knowledge. This is not a requirement for advancement, however it may influence the selection board (LT and above) favorably if an officer has completed some correspondence courses. Both the fleet and the Bureau of Naval Personnel have correspondence courses available. Fleet administered courses prepare the student for specific officer assignments, such as officer of the deck, weapons officer, and communications officer. BuPers administered courses take up technical subject areas such as military justice, naval engineering, damage control, and the like. It's best for an officer to take courses voluntarily, but his commanding officer may require him to take certain course—for example, if the ship hasn't enough navigators, you may be required to take the navigator course so that you can qualify without delay and alleviate the shortage. Since in normal practice an officer can take only one course at a time, and completion of a course may take a year or more, it is clear that a career-conscious officer must plan far ahead—even if he is an ensign and his name is not scheduled to go before a selection board for promotion. BuPers publishes lists of Navy correspondence courses. USAFI publishes lists of correspondence courses with subjects at both high school and college levels, and a list of correspondence courses available from civilian colleges and universities cooperating with USAFI.

2. POSTGRADUATE COURSES. The Navy has arrangements for officers with some experience to take postgraduate training on college campuses (which may lead to a degree) or at the Navy postgraduate school at Monterey, California.

3. OTHER NAVY SCHOOLS. The Navy has other officer training courses on specific subjects such as damage control or defense against nuclear, bacteriological, or chemical (NBC) attack. These are generally much briefer than the first two types of courses mentioned above, and are offered by BuPers.

The next section in this chapter will indicate the self-training and orientation that the junior officer should consider himself responsible for when he first reports aboard his ship.

SHIPBOARD TRAINING

Now let us see how the Navy's training programs fit into the Navy career patterns. Both shipboard training and training in Navy schools have individual training and team training aspects.

Individual training aboard ship is concerned with such activities as taking correspondence courses, and sometimes even (especially aboard larger ships) with organization of formal classes. Usually, however, individual training in which an instructor teaches students occurs in such situations as where an FT1 or FTC teaches a couple of strikers how to tear down an instrument servomechanism, or to troubleshoot a malfunctioning electronic circuit, etc. In addition to such job training, both enlisted and officer personnel can take broader courses offered by USAFI; for example, many men who did not finish high school before they joined the Navy have done so through USAFI.

Navy schools are also a form of individual training. School attendance is required for advancement in rate in certain ratings. In highly technical ratings, such as FT and ET, it is almost a must. Schools are always desirable and helpful for advancement in rating. A man who graduates from a Navy school is valuable to the Navy and at the same time helps himself get ahead.

Team training on board ship may be either operational or in maintenance work. (The latter would include such work as boresighting or other battery alignment operations which require a team of men working together.) Operational training can occur either aboard ship or ashore, and may involve a team of almost any size. Aboard ship, operational team training includes such activities as GQ drill, loading drill (on gun mounts), drills in various bills, and CIC drill. Operational drills have enormous potential training value. However, for the value to be realized, the leaders of the drill (and this quite often means the junior division officer or the division officer) must function imaginatively, but with a lively sense of the businesslike purpose of the drill. Other operational training includes gunnery exercises, multiship exercises (such as ASW drill), and the like. One aspect or another of team training will, in fact, dominate your duty hours aboard ship,—or if it doesn't, it should. It is consequently the aspect of your work as division officer that should get maximum attention, and certainly the maximum amount of constructive thought.

Fortunately, team training can go on even when the crew is not on board ship. All ships must periodically go to a tender or naval shipyard for overhaul and heavy maintenance work.

Yard work generally means several weeks in which the ship, even if not actually in drydock, cannot be operated because its machinery and armament are partly or completely disabled, and there is no ammunition or fuel aboard. During this period, even if a portion of the crew is on leave, some may be sent to fleet training schools which specialize in specific weapons such as the 3"/50. Other fleet training activities ashore give quick, intensive short courses (aboard "school ships" temporarily assigned for this purpose, or in shore facilities) in CB plot operations, CIC, spotting, etc.

Following every yard period comes a period of underway "refresher" training (generally for 5 to 6 weeks) in which the crew (many of whom have been replaced during the yard period) goes through a complete series of training sessions at sea, while at the same time the ship is put through its paces to check its overhaul. This culminates in the Operational Readiness Inspection (ORI) in which officers from the highest echelons of the Fleet check the ship and its crew in every aspect of operational preparation. Although we have called the ORI a "culmination" of underway refresher training, this by no means implies that the training program can come to a standstill; it is in fact only the beginning of a continuous, endless process.

You as a junior division officer or division officer will have your area of responsibility in every training program that affects the weapons department—and few do not affect it.

WEAPONS EXERCISES

One of the most important aspects of team training is the weapons exercise. The most important objective in weapons exercises is to train personnel in the most effective use of the ship's armament. Another important objective is the development of new doctrines, techniques, and procedures to keep pace with new targets and new equipment. Hence the conditions under which they are held are made as realistic as possible, to eliminate artificialities which might lead to false conclusions.

Publications promulgated by CNO prescribe the weapons exercises now used in the fleet. Separate publications prescribe the training exercises, procedures, and reports required, including outlines of the specific tactical situations which precede the firing. These publications are confidential, and are in the custody of the Registered Publications System (RPS) Custodian. They may be signed for and drawn for study. Frequent reference to the weapons department files will keep the officer posted concerning past weapons performance as well as current doctrines and procedures.

Just as important as the firing exercise operations themselves are the reports that must be made of the operations, and the analysis of the reports. Too frequently reports of weapons exercises lose their significance and serve merely to represent additional paper work to the junior officer. Remember that it is necessary to make an accurate appraisal of the effectiveness of the ship's armament, and that to do so requires careful, detailed analysis of accurately compiled reports.

Sufficient data must be taken during the exercise to permit postfiring analysis. It must be carefully assembled and even more carefully checked. If the report indicates an ineffective battery, every last detail must be scrutinized to ascertain the cause—which must then be corrected.

EFFECTIVE NAVAL LEADERSHIP

"Leadership lights the way. Ignore it and your limit is the work of your own two hands. Learn it, and your limit is the world and the sky above it." The above quotation (of unknown origin, and not to be taken literally) emphasizes what leadership can accomplish.

Naval leadership means the art of accomplishing the Navy's mission through people. Effective leadership is based on personal example, good management practices, and moral responsibility. The United States Navy has long been distinguished for the high quality of its officers and men. The following discussion points out the requisites of being a leader, for improving on leadership capabilities, and for exercising leadership qualities.

THE LEADER

Few people are born leaders. The majority of leaders (in civilian life as well as in the military) have utilized their innate abilities to best advantage, learned their jobs thoroughly, and applied common sense to the task at hand. These men have thus earned for themselves the respect, admiration, and loyalty of their superiors and subordinates alike—they have become leaders.

The best military leaders are characterized by patriotism, valor, integrity, ability, initiative, imagination, judgment, loyalty, dependability,

tact, self-control, and, above all, a "can-do" attitude to accomplish a mission despite the obstacles.

Don't let this formidable list daunt you. Leadership is a prerequisite to success, and fortunately most men willingly accept direction from their seniors.

LEADERSHIP DURING OFFICER TRAINING

The Navy cannot produce all-around leaders in the various officer candidate schools (the U.S. Naval Academy, NROTC Schools, OCS, ROC, etc.); it can give them the best leadership education possible at the academic level. Beyond this, you can become a good and successful leader only from practice and training aboard your ship or station.

As college students in the NROTC program or candidates in OCS, you should be developing your leadership potential. If you aren't, now is the time to start working at it. Leadership is not bestowed upon anyone automatically upon graduation or through being sworn in as a commissioned officer. Leadership must be learned through exercise.

LEADERSHIP ON BOARD SHIP

Leadership has been defined many ways. One popular version is: "The ability to have others do what you want them to do because they want to do it."

The naval weapons concept that you have studied doesn't eliminate the individual; paradoxically it increases the responsibilities and capabilities required of the operating personnel. The effectiveness of any weapon system depends on the knowledge and operation of the component parts of the system by the operating personnel. As a result, the junior officer has to be a combination technician, tactician, leader, and follower.

Why is the "can do" attitude so important? Because it's results, not technical potentials, that count. The command that utilizes its equipment to maximum effectiveness will defeat a more technically advanced adversary whose personnel are not as proficient employing its weapons to maximum effectiveness.

We can never afford to blame our technical and tactical ineptness on equipment. Nor can we rationalize that better equipment will make up for our shortcomings. Former Chief of Naval Operations Admiral Arleigh Burke emphasized on many occasions that "the fleet must always do the best with what it has."

LEADERSHIP FOR THE JUNIOR OFFICER

As a junior officer you may be assigned tasks below your potential. This is a normal evolution—minor responsibilities diligently and efficiently performed lead to more challenging and interesting assignments. It is commendable and essential to set a high goal to strive for, but the higher the goal the more devoted and patient you must be. There is always room for one more industrious, conscientious, imaginative officer in any wardroom. Learn your own job regardless of what it may be. Prepare yourself for additional responsibilities and it won't be long before you will be fleeted up as a department head.

The standards of the Navy are set by your superiors, but the successful attainment of those standards depends upon the cooperation of the junior officer in insuring that those standards are understood and complied with.

As a junior division officer in the weapons department—or any department for that matter—you will find that you are expected to learn on the job and perform tasks that you were not adequately taught. Junior officers' ability to learn on the job affects the operations of a department in a large combat ship—but it can make or break the entire command the size of a destroyer.

The Navy shows great tolerance and forebearance to the junior officer who conscientiously and industriously carries out his duties, who is not afraid to dig for the information he needs, and who in every way evidences a sincere desire to do his best as a naval officer. Every ship's complement is composed of such numbers, ranks and ratings of officers and men as are required to operate the ship most effectively in war and in peace. There is never room for deadwood. Keep in mind what Admiral Sims once said, "We believe it is the duty of every officer to study his own character that he may improve it, and to study the characters of his associates that he may act more efficiently in his relations to them."

APPENDIX I

GLOSSARIES

This appendix is in two parts. The first part is a general glossary which lists in alphabetical order some terms and abbreviations used in this text, plus a few others. The second part is an alphabetical listing of all surface and AA gun fire control symbols—each with a brief explanation—in common use at the present time.

The general glossary is intended as a convenience to the student in home study and other situations where standard authoritative Navy reference sources are not readily available. It is not intended to supplant or supersede authoritative sources. Nor should it be used for general reference. The definitions of most of the terms and symbols included in this appendix, regardless of what they denote in general use or in other technical areas, apply primarily to Navy usage.

To avoid inconvenient length, the glossary entries are mostly brief and do not usually go into detail regarding derivations, shades of meaning, limits of application, etc. For further information on any entry, or for information on any term not in the glossary, you should look it up in the index to determine if there is further discussion in the text and should then go to other reference sources if necessary.

PART I—GENERAL GLOSSARY

AA: Antiaircraft.

AAC: Antiaircraft common (projectile).

Aberration: Distortion in optical lens or mirror.

a-c (or a.c.): See alternating current.

AC Device: In mines, an anticountermining device that prevents a mine from detonating because of a nearby explosion.

ACP: See NWP.

Acquisition: The process of accepting a designation, acquiring the target, and initiating target tracking.

ACTR: See Arbitrary Ballistic Correction.

Actuation Counter: A device used to complete the electrical circuit to the mine detonator after a preset number of firing system actuations.

ADF: Auxiliary detonating fuse.

Advance Range: Present range combined with the corrections and predictions necessary to compensate for own ship and target motion during the time of flight, plus ballistic corrections and spots.

A-End: The variable-output pump in a hydraulic speed gear.

AF: Audio frequency, especially with regard to sonar signal fed to loudspeakers or headphones.

Afterbody: The part of a torpedo between the midship section and the tail. Usually contains propulsion and guidance equipment.

Aiming: The process of establishing target position in bearing and elevation.

A. Aim is classified as to TYPE by the instrument employed:

1. Radar Aim describes determination of target bearing and elevation by radar.
   a. Partial Radar Aim describes determination of bearing by radar and determination of elevation by stabilizing equipment.
2. Optical Aim describes determination of target bearing and elevation by optical instruments.
   a. Partial Optical Aim describes determination of target bearing by optical instrument and elevation by means of stabilizing equipment.
3. Generated Aim describes the generation of target bearing and elevation, and corrections thereto for deck inclination, by means of a computer and stabilizing equipment.

B. Aim is classified as to METHOD by the manner in which the aiming system is operated.
  1. Continuous Aim describes continuous measurement of target position in bearing and elevation.
     a. Continuous Automatic Aim describes automatic continuous aiming instrument.
     b. Continuous Aided Aim describes continuous aiming with the aiming instrument positioned by signals received from the computer and with the resulting position corrected by the operators.
     c. Continuous Manual Aim describes continuous aiming with the aiming instrument positioned by hand, using either direct manual drive or local power.
  2. Intermittent Aim describes periodic measurement of target position in one element and continuous measurement in the other.
     a. Selected Elevation describes determination of target position continuously in bearing and intermittently in elevation.
     b. Selected Train describes determination of target position continuously in elevation and intermittently in train.

Airborne Early Warning (AEW): AA search by craft other than own ship.

Airburst:
  1. An explosion of a bomb or projectile above the surface, as distinguished from an explosion on contact with the surface or after penetration.
  2. The explosion of a nuclear weapon in the air at a height greater than the maximum radius of the fireball.

Air Flask Section: In an air-steam torpedo, the midship section.

Air-Steam Torpedo: A torpedo propelled by a turbine engine driven by a mixture of air and steam.

Alternating Current (a-c is the abbreviation used in this text; other texts may use a.c.): Current (or voltage) that periodically reverses polarity in a circuit. Commonly, if the value is plotted on a graph against time, the result will be a more or less smooth sine wave; this is the characteristic output waveform of transformers and generators. Alternating current supplies on ships are generally either at 60 Hz or 400 Hz.

Altitude: The vertical component of slant range. (Since this definition disregards the curvature of the earth, it should not be applied beyond the limits of present gun fire control systems.)

Amatol: A mixture of ammonium nitrate and TNT.

Ammunition: A contrivance charged with explosives, propellants, pyrotechnics, initiating composition, or nuclear, biological, or chemical material for use in connection with defense or offense, including demolitions.

Ammunition Details: Components of a round of ammunition.

Amplidyne (Generator): A highly variable-output d-c generator identified with this trade name.

Amplidyne System: A system in which a small signal regulates output of a d-c amplidyne generator that feeds a servo motor.

Amplifier (Electronic): A device that uses a component such as a transistor or electron tube to increase the magnitude (of voltage, current, or power) of a signal.

Amplitude: Distance through which a particle is displaced in vibration; a measure of amount of vibration.

AN/: Army-Air Force-Navy designation.

Analog Computer: A computer which solves a certain type of problem by using electrical or mechanical analogs whose end output represents the solution. Cf. Digital computer.

Angle of Climb or Dive: The vertical angle between the horizontal and the direction of motion of the target measured in degrees at the target.

Angle of Incidence: Angle between an incident light ray and the normal at an optical surface.

Angle of Reflection: Angle between normal and reflected ray.

Annunciator: An alerting device used to indicate to personnel that target designations are pending.

Antisubmarine Barrier: The line formed by a series of static devices or mobile units arranged for the purpose of detecting, denying passage to, or destroying hostile submarines.

Antisubmarine Warfare (ASW): Operations conducted with the intention of denying the enemy the effective use of his submarines.

Antisubmarine Warfare Forces: Forces organized primarily for antisubmarine action. May be comprised of surface ships, aircraft, submarines, or any combination of these and their supporting systems.

Apparent Mean Dispersion of a Salvo in Range (or deflection): The arithmetical average of the dispersion in range (or deflection) of the several shots of the salvo, excluding wild shots.

Apparent Wind: Wind apparent at the observing station; the resultant of the true wind and the motion of the observing station.

Arbitrary Ballistic Correction: An empirical correction in range or deflection to compensate for all indeterminate errors in the fire control problem. It is obtained from an analysis of previous firings. This is commonly referred to as ACTH (arbitrary correction to hit).

Area Fire: Support gunfire delivered to a prescribed area. Usually used in neutralization support fire.

Armament: See Ordnance.

Armature Reaction: Magnetic field produced by induced armature current in a d-c generator.

Arming: As applied to explosives, the changing from a safe condition to a state of readiness for initiation.

Arming Wire: A wire harness used to initiate arming of a weapon.

A/B Scope: A type of fire control radar display.

A/S: Antisubmarine (adjective).

Asroc: AntiSubmarine ROCket. A surface ship-launched, rocket-propelled, nuclear depth charge or homing torpedo.

Astor: AntiSubmarine TORpedo. A submarine-launched, long-range, high-speed, wire-guided, deep-diving, wakeless torpedo capable of carrying a nuclear warhead for use in antisubmarine and antisurface ship operations.

ASW: Antisubmarine warfare.

ATP: See NWP.

Attack Director: Electromechanical analog computer used to solve underwater fire control problem.

Attrition Mining: Mining primarily for the purpose of destroying enemy ships.

Audio: Audible signal, or electrical signal that eventually is used in production of audible signal.

Autofrettage: A method for prestressing gun barrels by radial expansion.

Auto(matic) Control: Control of a gun mount entirely and directly through remote signals from a fire control system.

Automatic (Gun): Case gun in which some of the propellant's energy is used to open the breech, eject the empty case, and load the next round.

Auxiliary (Explosive or Propellant): Substance used in intermediate stages in an explosive train.

Axial-Piston Pump: A pump that consists of a group of cylinders in a barrel, arranged parallel to the axis of the barrel's rotation.

Axis of Bore: The extension of the central axis of the gun bore. It is tangent, at the muzzle, to the trajectory of a projectile fired from the gun.

AXP: See NWP.

Azimuth: The horizontal angle in mils measured from grid north to the OT (observer-target) line.

Azimuth Search Sonar: Sonar system that radiates transmitted pulse in all directions and searches spirally in 360° of azimuth.

Bag Ammunition: Gun ammunition with propellant in fabric bags and with separate projectiles and primers.

Ballistic Corrections: Corrections in range and/or deflection to compensate for known or predicted errors, for drift, for wind, and for all variations from standard range-table conditions.

Ballistic Cross Wind: The horizontal component of the ballistic wind at right angles to the target bearing.

Ballistic Density: The single air density, determined by computation, which would have the same range effect on the projectile as the actual densities throughout the trajectory.

Ballistic Missile: A guided missile designed to follow for a substantial part of its flight a ballistic (free or unsteered) trajectory.

Ballistic Range Wind: The horizontal component of the ballistic wind parallel to the target bearing.

Ballistics: The science that deals with the motion, behavior, appearance or modification of missiles or other vehicles acted upon by propellants, wind, gravity, temperature or any other modifying substances, conditions or forces.

Ballistic Trajectory: The trajectory traced after the propulsive force is terminated and the body is acted upon only by gravity and aerodynamic drag.

Ballistic Wind: The effective wind, determined by computation, of such force and direction that its action on the projectile during the time of flight will be the same as the combined actions produced by the various true winds acting in the strata through which the projectile will pass as it moves along the trajectory.

Barrage: Barrier of fire executed on predetermined firing data. The initial shots are placed across the probable path of the target.

A. Barrages are classified as to method by the manner in which position of the bursts is varied.

1. Line-of-Sight Barrage is a barrage using fixed fuse setting and varying sight settings, with each shot so directed that bursts will occur in the instantaneous line of sight to the target.
2. Fixed-Zone Barrage is a barrage fired with fixed sight settings. Once the target has passed through the zone of fire, a second zone may be selected and a new barrage fired.
3. Creeping-Zone Barrage is a barrage in which the fuse settings are varied in such a way as to advance along the track slower than the actual target advance.

Barrel (Gun): Part of gun structure that contains the bore.

Base Length (of Rangefinder): Distance between windows.

Base Ring: Base section of rotating structure of gun or rocket mount. Also called "deep section ring" or "lower carriage."

Base Surge: A cloud which rolls out from the bottom of the column produced by a subsurface burst of a nuclear weapon. For underwater bursts the surge is, in effect, a cloud of liquid droplets which has the property of flowing almost as if it were a homogeneous fluid. For subsurface land bursts the surge is made up of small solid particles but still behaves like a fluid.

Basic Mechanisms: Elementary components of machinery, including various basic machines.

Bathythermograph: A recording thermometer that shows water temperature at various depths.

Batten Board: Flat screen with target markings, sometimes used in boresighting.

Battery: All guns, torpedo tubes, searchlights, or missile launchers of the same size or caliber are used for the same purpose, either installed in one ship or otherwise operating as an entity.

Battery Alignment: Alignment of weapons and fire control equipment to a common system of reference lines and planes under specified conditions.

Battery Compartment: In an electric torpedo, the midship section.

Battery Control: The direction of the employment of all the mounts or turrets of a similar caliber or purpose in a vessel. It is concerned with the disposition of the mounts or turrets with respect to the fire control stations of the battery, the interior communications plan to be used, the designation and acquisition of targets by the battery or group, and the standard procedures to be employed. The Battery Control Officer is assisted by Group and Sector Control Officers, and by CIC Weapons Liaison Officers.

1. Battery Control is classified as to type by the manner in which the command of the battery is exercised.
   a. Collective Battery Control is that type of battery control in which the direction of the employment of the battery is centralized.
      (1) Divided Battery Control is that form of dispersed control wherein a battery with two directors is divided into forward and after batteries for command purposes. This form of control is associated with centerline, single purpose batteries.
      (2) Sector Battery Control is that form of dispersed control in which a battery with multiple directors is divided into sectors for control purposes.
2. Battery Control classified as to method prescribes the grouping of the mounts or turrets with fire control stations, command communications channels between fire control stations, and procedures for designation and acquisition. For a particular vessel the groupings are prescribed in the battle bill.

Battery Position: Recoiling parts of gun in position for gun to fire.

Battle Announcing System: A system of microphones, amplifiers, and loudspeakers used for internal communication aboard ship.

Battle Bill: A table listing stations to be manned and personnel required under battle conditions aboard ship.

Battle Control Stations: Primary key points of ship's battle organization.

Battle Telephone: Sound-powered telephone.

Bazooka: A small infantry-launched rocket originally designed as an antitank weapon.

BDF: Base detonating fuze.

Beach Defense Mine: Bottom mine laid in shallow water to destroy landing craft.

Beacon:
1. A self-propelled noisemaker ejected by a submarine to distract A/S attack.
2. A radar signal transmitter used to establish a reference point or for other purposes. (Also called Racon.)

Beam Rider: A missile guided by a radar or radio beam.

Bearing Rate: Rate of change of target bearing from own ship caused by the relative motion of own ship and target. It may be expressed in knots (linear measure) or in degrees per minute (angular measure).

Bell (Gun): Thick part of gun muzzle (not on all guns).

Bench Mark: In battery alignment, a reference point on own ship structure used for aligning battery directors.

B-END: The hydraulic motor in a hydraulic speed gear.

Bill: A written directive that prescribes a procedure for performing some operation, or dealing with some specific situation. It lists what is to be done, material needed, and who does it.

Billet: A specific duty or station assignment to which an individual may be named, or a combination of such assignments to which a single individual is named.

Billet Number: A code designating a crewman's division, section, and precedence.

Binary: Having only two alternatives, such as, ON or OFF. (A binary number consists of 1's and 0's. The binary numbering system uses the base 2; the decimal numbering system uses the base 10.)

Biological Weapon: An item of material which projects, disperses or disseminates a biological agent including arthropod vectors.

BL: Blind-loaded projectile. Equivalent to plaster-loaded or sand-loaded.

Black Powder: An explosive mixture (used usually as an auxiliary) made up of carbon, sulfur, and saltpeter.

Blank Ammunition: Gun ammunition lacking projectiles.

Blasting Cap: Demolition charge initiating device.

Blind Time: Time lapse from instant of firing of an A/S weapon till it reaches predicted position of submarine target.

Blip: Element of radar or sonar video presentation. Also called "pip."

Blipology: Interpretation of cathode-ray tube displays.

Blowback: Escape, to the rear and under pressure, of gases formed during the firing of the gun. Blowback may be caused by a defective breech mechanism, a ruptured cartridge case, or a faulty primer.

Bomb: A missile containing explosive or chemical filling generally dropped from an aircraft.

Booster:
1. A unit in an explosive train which causes detonation of the main charge.
2. An auxiliary or initial propulsion system which provides initial thrust.

Boresafe (Fuze): A fuze designed to arm only after the projectile passes the gun muzzle.

Boresighting: Adjusting sights to be parallel with gun bore axis or to make their lines of sight intersect gun bore axis at some specified range.

Bottom Mine: A mine designed to be laid on sea bottom. Formerly called ground mine.

Bourrelet: Annular part of a projectile forward of the rotating band.

Bracketing: A method of adjusting fire in which a bracket is established by obtaining an over and a short along the spotting line, and then successively splitting the bracket in half until a target hit or desired bracket is obtained.

Breechblock: Gun mechanism element that blocks chamber when gun is fired. Also called "plug."

Brisance: Rapidity with which an explosive develops its maximum pressure.

Brush: Contact used with slip rings and commutators.

B-Scope: A type of fire control radar display.

BT: Abbreviation for bathythermograph.

Built-up (Gun): A type of prestressed gun barrel.

Burnout: The point in time or in the missile trajectory when combustion of fuels in the rocket engine is terminated by other than programmed cutoff.

Burster: Bursting charge or explosive load in a projectile, mine, torpedo, etc. Final unit in an explosive train.

Caliber: Nominal diameter of projectile or rifling gun bore, or diameter of rocket head.

Call Fire: Fire delivered on a specific target in response to a request from the supported unit.

Call for Fire: A request for fire containing data necessary for obtaining the required fire on a target.

CAP: Combat Air Patrol.

Capacitance (C): The property of a particular type of electrical nonconductor that permits it to store energy when opposite surfaces of the nonconductor are maintained at different voltage potentials.

Carbamite: A stabilizer used in SPCG.

Carrier Striking Force: A naval task force composed of aircraft carriers and supporting combatant ships capable of conducting strike operations.

Cartridge Case: (See Case Ammunition.)

Case Ammunition: Gun ammunition with propelling charge and related components in a metal or plastic cartridge case.

Cavitation: Formation of partial vacuum on certain parts of fast-rotating ship screws; this causes inefficiency and considerable acoustic disturbance.

CD Mechanism: In mines, a clock delay device to delay arming for a period after planting.

Cellulose Nitrate: (See Pyrocotton.)

Center of Burst: A point about which the bursts of projectiles fired under like conditions are evenly distributed.

Central Amplifier System: A type of battle announcing system.

Centrifugal Force: In a rotating object, radial thrust away from center of rotation caused by inertia.

Chamber (Gun): That part of the gun in which the propelling charge is located when the gun is ready to fire.

Chase (Gun): (See Gun Chase.)

Chemical Agents: Substances used in munitions for signaling, screening, asphyxiation, or chemical attack. The three main varieties of chemical agent are war gases, smokes, and incendiaries.

Chemical Torpedo: A type of air-stream torpedo that uses hydrogen peroxide to support fuel combustion.

Chronograph: Any of several devices used to measure and record velocity of a gun projectile after it leaves the muzzle.

CIC: See Combat Information Center.

Closed-Circuit Television: (also Closed-Loop Television) A television installation in which the signal is transmitted by wire to a limited number of receivers.

Closed-Loop Servo: A servosystem in which a servomotor is employed to amplify a comparatively weak signal. It is composed of an error detecting device, an error signal amplifier, and a motor. Input signals and the response of the motor are compared by the error detecting device. The resultant error is amplified and drives the motor. The motor rotates in such a direction as to cancel the error signal.

Close Support Area: Area between friendly front lines ashore and the near limits of zones of responsibility.

Close Support Fire: Fire placed on enemy troops, weapons, or positions which, because of their proximity, present the most immediate and serious threat to the supported unit.

Closure Mining: Mining primarily for the purpose of preventing passage of enemy ships.

Cock: A plug type valve seated in a pipe. A pet-cock is generally used to open or close a drain or other type of exhaust opening in a system.

Collimating Lens: A lens used to produce parallel light rays.

COM: Common (projectile).

Combat Information Center (CIC): The agency in a ship or aircraft manned and equipped to collect, display, evaluate, and disseminate tactical information for the use of the flag officer (if embarked), commanding officer and certain control agencies. Certain control, assistance and coordination functions may be delegated by command to the Combat Information Center.

Combustion Flask (Torpedo): Compartment in which fuel-air mixture burns.

Commutator: Rotating contact system consisting of a ring-like arrangement of insulated metal bars, or other groups of discrete contacts which are touched sequentially by a brush as a rotor turns.

Compensator Wedges: Thin optical prisms used in optical rangefinder.

Complete Round: All ammunition details required to fire one shot.

Compression Waves: See Longitudinal Waves.

Concentration Area: A limited area on which a volume of gunfire is placed within a limited time.

Conditions of Loading: In interior ballistics, the powder used, the weight of charge, the density of loading, the volume and shape of the powder chamber, and projectile weight.

Condition Watch: Aboard ship, a personnel disposition based on degree of readiness.

Conical Scan: In radar, a type of antenna beam scan used for target tracking. The scanning is characterized by having a fixed tilt angle. The axis of the radiofrequency beam generates a cone whose vertex angle is usually from five to ten degrees.

Conservation of Energy, Doctrine of: Except for nuclear reactions, the quantity of energy in the universe remains the same, but may be converted to different forms.

Constriction: Narrowed part of gun bore.

Contact: In AA or A/S search, a detected potential or actual target.

Contact Mine: Mine that will explode when target touches the mine or one of its sensitive components such as an antenna. Contact firing mechanisms may be mechanical, galvanic, or electrochemical.

Control: Authority, less than full command exercised over the armament or a portion thereof.

Control Indicator: See Sonar Control Indicator.

Controlled Mine: Mine controlled from a station ashore.

Control Units: See Weapon System.

Conventional Weapons: Nonnuclear weapons. Excludes all biological weapons, and generally excludes chemical weapons except for existing smoke and incendiary agents, and agents of the riot-control type.

Convergent Lens: A lens that causes parallel light rays entering it to converge.

Convoy: A formation of merchantmen (usually under naval protection).

Cool Propellant: Propellant that burns at relatively low temperature.

Coordinate Converter: An electromechanical instrument used to compute bearing and range from north-south east-west position. It can also compute the north-south east-west position from director train and range information.

Copper Fouling: Metal residue deposited in gun bore by erosion from rotating bands.

Cordite N: See SPCG.

COSAL: COordinated Shipboard Allowance List. An allowance list of consumable parts required to support a ship's on-board equipment. It is determined by a physical inventory of the on-board equipment on an INDIVIDUAL ship basis.

Counterbattery Fire: Support fire directed against enemy weapon emplacements for the purpose of silencing them.

Countermeasures: That form of military science which by the employment of devices and/or techniques has as its objective the impairment of the operational effectiveness of enemy activity.

Countermining: The detonation of mines by nearby explosions, either accidental or deliberate.

Counterrecoil: Movement of recoiling gun parts toward battery position. This is accomplished by a "counterrecoil mechanism" or "recuperator."

Counterrotation: Rotation in opposite directions.

cps: Cycles per second. (See Hertz.)

Creep: Forward thrust on fuze parts caused by gradual slowing of projectile in flight.

Critical Angle: At angles of incidence greater than the critical angle, all incident light is reflected back into glass. (This property is called "total internal reflection.") The value of the critical angle depends on the refractive index of the glass.

Crosshairs (or Crosswires): Reticle marks consisting of a pair of mutually perpendicular lines (horizontal and vertical).

Crosslevel Angle: Inclination of the battery reference plane with the horizontal, usually measured in a plane perpendicular to the plane in which level is measured. The latter plane may be either the vertical or a plane perpendicular to the reference plane, depending on the design of the control equipment.

CRT: Cathode-ray tube.

CS Mechanism: In mines, a clockstarter device that starts or stops the timing mechanism in the mine.

Cycle: An interval of time during which a sequence of a recurring succession of events or phenomena is completed, such as a complete performance of a vibration.

Cyclonite: See RDX.

Damping Generator: A-c or d-c motor-driven tachometer type generator in a servo system whose output opposes the signal which drives the motor. Also called "stabilizing" or "feedback" generator.

Danger Space: For a material target this is the distance in front of the target, measured parallel to the line of fire, that the target could be moved toward the firing point, so that a shot striking the base of the target in its original position would strike the top of the target in its new position.

Dash: Drone AntiSubmarine Helicopter. Small, lightweight, remotely controlled helicopter capable of operating from a destroyer and delivering an antisubmarine warfare weapon to an enemy submarine. It provides destroyers with a standoff weapon.

Dashpot: A hydraulic braking mechanism.

Data Transmission System: System (usually electrical) for conveying precise fire control and navigational data from one point to another.

Datum: In ASW, a reference point at which a submarine was last contacted.
D/C: See Depth Charge.
d-c (or d.c.): See Direct Current.
Dead Time: Time interval between fuze setting and firing of gun.
Decibel (db): Difference expressed logarithmically between two sounds, or a sound and an arbitrary reference level. N = 10 log A/B.
Decoppering: Process of removing copper fouling from gun bore.
Deep Section Ring: See Base Ring.
Deep Support Fire: Fire directed on objectives not in the immediate vicinity of our forces, for neutralizing and destroying enemy reserves and weapons, and interfering with enemy command, supply, communications, and observations.
Defensive Minefield: Mines laid to deny friendly waters to enemy.
Defilade Fire: Gunfire delivered on shore targets located behind some terrain feature.
Deflection: The lateral angular correction (converted to the deck plane where necessary) which is applied to the target bearing in the deck plane to obtain gun train order.
Deflection Modulation: A principle of radar indicator functioning in which the electron beam is deflected to show a blip.
Degaussing: A method of reducing a ship's magnetic field by use of several types of coils carrying direct current around parts of the ship's hull.
Degaussing Range: An installation containing magnetic sensing devices. Ships steaming past the sensing devices cause their signatures to be recorded.
Degree of Freedom: Ability to rotate on an axis.
Degree of Readiness: Status of ship's complement, plant, and armament under specific conditions.
Deliberate Attack (ASW): Concentrated attack to kill.
Delivery Device (in Weapon System): See Weapon System.
Demolition Agents: Explosives used in demolition equipment other than ammunition.
Density of Loading: Ratio of powder weight to that of a volume of water which will fill the powder chamber at a specified temperature.
Deperming: Reducing the permanent magnetic field of a ship's hull.
Depth and Roll Recorder: A device that records a torpedo's running depth and angle of roll during the run.
Depth Charge: An underwater explosive used against submarines.
Designate Knob: Visual representation of designated target position, used in some types of target designation systems.
Designation Indicator: An equipment which displays radar or television video on the face of a kinescope (cathode-ray tube).
Destruction Fire: Fire delivered for the sole purpose of destroying material objects.
Destructor: A small, special purpose explosive charge used to destroy equipment in danger of capture, and to destroy weapons for safety reasons.
Deterrence: The prevention from action by fear of the consequences. Deterrence is a state of mind brought about by the existence of a credible threat of unacceptable counteraction.
Detonation: Violent chemical action (oxidation and recombination) initiated by a shock and producing a shock wave, heat, and gases.
Detonator: Initiating device in an explosive train.
DI: Delayed ignition (tracer).
Differential:

a. Cylinder. A piston-cylinder hydraulic device used to develop either equal thrust with unequal pressure or unequal thrust with equal pressure.
b. Mechanical. A gear arrangement used to add or subtract mechanical inputs.
c. Synchro. Either of two types of synchros used to develop a mechanical or electrical difference between or sum of two inputs.

Digital Computer: A computer, mechanical or electrical, that performs mathematical operations by counting. Cf. Analog computer.
Diode: A two-electrode electron tube containing an anode and a cathode or a two-element semiconductor.
Dip: Apparent depression angle of the horizon at sea; varies with height above sea level. Dip difference is the difference in dip at different heights.
Dip Sonar: Airborne sonar equipment lowered into the water for sonar observations from hovering helicopter. Sometimes called "dunking sonar."
Diphenylamine: A stabilizing compound used to retard deterioration in single-based powder.
Dip-Needle Mechanism: A type of magnetic mine firing mechanism.
Direct Current (d-c is the abbreviation used in this text; other sources may use d.c.): Current (or voltage) that does not reverse polarity periodically. (See Alternating Current.) A direct current or voltage may fluctuate, or

it may be interrupted but it is still direct current.

Direct Fire: Gunfire delivered on a target ashore, visible to the firing ship, which uses the target itself as an aiming point.

Director: A fire control unit that establishes location of target and may furnish gun orders or other weapon positioning information.

Direct Supporting Fire: Fire delivered in support of part of a force, as opposed to general supporting fire which is delivered in support of the force as a whole.

Dispersion (of a Shot): The distance of the point of impact of that shot from the MPI of the Salvo. Dispersion in range is measured parallel to the line of fire, and in deflection at right angles to the line of fire in a horizontal plane.

Distress Signal: A dual-purpose pyrotechnic device.

Diversionary Attack: An attack wherein a force attacks, or threatens to attack, a target other than the main target, for the purpose of drawing enemy defenses away from the main effort.

Doctrine (Naval Warfare): A working principle or rule of combat that has been developed theoretically and proved by experience. Procedures are methods used to put the doctrine into effect.

Domain (Magnetic): See Magnetic Domain.

Dome: Underwater sonar transducer housing.

Doppler Effect: Apparent change of frequency of sound (or any other form of wave motion) when the source and the observer are in motion relative to one another.

Double-Base Powder: Solid rocket propellant usually composed chiefly of nitroglycerin and nitroguanidine.

Double-Speed (Synchro) Operation: Use of two parallel synchro systems, usually one operating at 1:1 ratio with input, and one at 36:1 ratio with input, for greater accuracy. Cf. Single-Speed (Synchro) Operation.

Dredger Hoist: A type of ammunition hoist used between handling rooms.

Drift: (1) Deflection of projectile trajectory by interaction of gravity, air resistance, and projectile spin. (2) Rate at which water current flow moves a ship with respect to the land. (See also Set.)

Drifting Mine: A mine with no provision for maintaining a fixed position after planting. It is free to move with the waves, current, and wind. Drifting mines may watch at the surface or may be kept at a set depth by depth control devices. They are to be distinguished from floating mines which are moored mines that have broken loose. Drifting mines are no longer used by the United States.

Drone: A vehicle—land, sea, or air—which is remotely or automatically controlled.

DRT: Dead-reckoning tracer. An electromechanical automatic plotting-tracking device which continuously displays own ship position and track on a chart. Some types may also show own ship heading.

Dummy Director: Test servo (usually synchro) signal generator.

Dummy or Drill Ammunition: Ammunition without explosive or propellant.

Early Warning: Target information obtained before radar or optics aboard own ship acquires the target. Early warning data may be transmitted from picket ships, AEW system, radio communications, shore based observers, or operational orders.

Echo: The signal reflected by a target to a sonar or radar set to indicate target position.

ECM: Electronic countermeasures.

Effective Range: The maximum distance at which a weapon may be expected to fire accurately to inflict casualties or damage.

Effort Arm: Distance on lever arm from fulcrum to point at which effort thrust is applied.

Electrical Firing: Firing a primer by electricity.

Electrical Resolver: A special type of rotating induction device which can function as a component solver or vector solver. It contains two rotor windings 90 electrical degrees apart and two stator windings also 90 electrical degrees apart. The resolver may be used for the following purposes:

1. Resolution—to solve vectors for right angle components.
2. Composition—to combine right angle components to produce a vector.
3. Combination—to combine several vectors to produce a single sum vector.

Electric-Setting Torpedo: Torpedo whose control settings are made through servomechanisms and relays which remain connected to the fire control system until the instant the torpedo is fired.

Electric Torpedo: Unless the context clearly indicates otherwise, this term conventionally denotes a torpedo equipped with electric propulsion gear. It does not denote "electric setting" unless the context requires it. For the sake of clarity, the ambiguous term "electric torpedo" is best avoided.

Electron Tube: A device in which conduction of electricity is provided by electrons moving through a vacuum or gaseous medium, within a gastight envelope.
Elevating Arc: Gear sector on slide used to elevate gun.
Elevating Gear: Mechanical, hydraulic, and electrical equipment used for elevating a weapon.
Elevating Nut: Part of a screw type gun elevating mechanism.
Elevation: Movement of a weapon in a plane perpendicular to the deck. Also properly called "pointing."
Elevation Alignment: Adjustment of fire control and weapon system elements so that they are in effect all parallel and all at exactly the same angle to a selected horizontal plane.
Elevation Rate: Rate of change of target elevation (position angle) in degrees per minute.
EMF: Electromotive force: usually equivalent to voltage.
Enabling (of Torpedo): Activation for pattern running or homing; in latter, exploder is also armed.
Enabling Run:
1. The straight portion of a pattern-running torpedo's run.
2. The portion of a homing torpedo's run that ends when the search pattern starts.
Energy: Capacity for Doing Work: Kinetic energy is energy in being, as that of a falling projectile or burning propellant. Potential energy is energy that can be released, such as that in a chemical propellant that has not been fired, or in a projectile about to descend from the peak of its trajectory.
Enfilade Fire: Gunfire on a ground target whose long axis is parallel to the line of fire.
Equivalent Service Rounds (E.S.R.): Standard unit of measurement of number of rounds fired from a gun for purposes of estimating resultant wear.
Erector (Lens or Prism): Optical element which inverts a real image.
Erosion (Gun): Wear in a gun bore.
Error of the Mean Point of Impact: The distance of the MPI from the target or other reference point, measured parallel to the line of fire for range and at right angles to the line of fire for deflection.
Error Recorder: Recording device used to show servo system performance.
Error Signal: In a servo, the difference between order signal and response. Error signal is fed into the servo's amplifying device.
E-Scope: A type of fire control radar display.

ETF: Electrical time fuze.
Ethyl Centralite: See carbamite.
Evaluation of Weapon System or Component: Study and appraisal of effectiveness of weapon system or component.
Exercise Head: That section of a drill torpedo or mine filled with inert and instrumentation materials, which enables training of personnel and recovery of weapon for evaluation.
Exploder: In a torpedo, the analogue of a projectile fuze.
Explosion: See Detonation.
Explosive: Any material that can detonate and is commonly used so that it will detonate.
Explosive D: Ammonium picrate. A notably insensitive explosive.
Explosive Ordnance Disposal Unit: Personnel with special training and equipment who render explosive ordnance safe (such as bombs, mines, projectiles, and booby traps), make intelligence reports on such ordnance, and supervise the safe removal thereof.
Explosive Train: Explosive units designed to function in sequence.
Exterior Ballistics: See Ballistics.
Exudate: Explosive oily substance, potentially dangerous, given off by cast TNT in storage.
Eyepiece (Lens): See Ocular Lens (Telescope).
Fairing: Structural additions to improve streamlining.
Fanfare: A device towed by surface ships to produce a false signal to distract enemy submarines.
Farad (f): Basic unit of capacitance measurement. The farad is too large a unit for practical work, so two smaller units — microfarad and picofarad (micro-microfarad) — are generally used. A microfarad is equal to one-millionth of a farad, and a picofarad is equal to one-millionth of a microfarad.
Feedback (Servosystem): Signal from servo output fed back to input to regulate servo action.
FFAR: The 2.75-inch folding-fin aircraft rocket.
Fin-Stabilized Rocket: A rocket stabilized by aerodynamic surfaces on its tail.
Fire Control: The organized system by means of which the offensive power of armament is controlled.
1. Fire Control is classified as to type by the system employed. For each type of fire control, the battle bill of the ship specifies the instruments to be employed.
   a. Primary Fire Control. The system provided to control before damage occurs to this system; it prescribes the utilization of the principal system.

b. Secondary Fire Control. An alternate system to give greater flexibility of control.
c. Auxiliary Fire Control. A system provided solely to substitute for a primary system in case of damage.
d. Local Fire Control. Control of a single gun mount or a turret from a local station in or adjacent to the mount or turret.

2. Fire Control is classified as to method by the procedures employed in the direction of the fire of the battery.
   a. Direct Fire Control. The control procedure employed when the target is observed from the firing vessel visually or by radar.
   b. Indirect Fire Control. The control procedure employed when the target is unobserved by the fire control instruments of the firing vessel.
   c. Offset Fire Control. The control procedure employed when a point of aim of known relationship to the target is observed from the firing vessel.

Fire Control Computer: Electronic or electromechanical device which receives mathematical data and puts out fire control problem solution data. Alternately some types may be called "rangekeeper."

Fire for Effect:
1. Fire which is delivered after the mean point of impact or burst is within the desired distance of the target or adjusting/ranging point.
2. Term in a fire message to indicate the adjustment/ranging is satisfactory and fire for effect is desired.

Fire Mission:
1. Specific assignment given to a fire unit as part of a definite plan.
2. Order used to alert the weapon battery/area and indicate that the message following is a call for fire.

Fire Support Area: An appropriate maneuver area assigned to fire support ships from which to deliver gunfire support of an amphibious operation.

Fire Support Group: A group of ships in an attack force, assigned a naval gunfire support mission.

Firing Cutout Mechanism: A device to protect own ship structure from being fired on by own ship weapons.

Firing Lock: A mechanical unit, part of the gun, which houses the firing pin or striker which contacts or strikes the primer.

Firing Pin: Metal pin that can fire primer either by electrical contact or by percussion.

Fishtailing: The weaving action of a torpedo as its steering engine throws the rudder over to right and left alternately to keep it on course.

Fixed Ammunition: Ammunition in which the cartridge case is permanently attached to the projectile.

Fixed Tubes: Torpedo tubes that cannot be trained with respect to the ship's structure.

Flammable Agent: See Inflammable Agent.

Flareback: Ignition of residual gases in a gun bore just after firing.

Flask Pressure Air: Air supplied direct from the torpedo air flask without reduction of pressure.

Flight Gear: In mines, any of several braking devices to reduce water impact of mines dropped from aircraft.

Floating Mine: Any mine which has broken loose from its mooring and floated to the surface. This is to be distinguished from a drifting mine which never was moored.

Fluid: A material that continuously adapts its shape to fit its container. Unless otherwise indicated, in this text the term "fluid" is equivalent to "liquid," but not to "gas."

FM:
1. Chemical agent. (See Lacrimator.)
2. A type of radio transmission in which carrier frequency is modulated.

Focal Distance (or Focal Length): Distance from center of lens to focal point.

Focal Point (Of Convergent Lens): Point at which parallel rays entering lens will meet after they emerge.

Follow-Up: See Servo.

Force: A pull or push on a material object that causes or tends to cause the object to move or (if moving) to change its direction or rate of motion.

Forcing Cone: See Origin of Rifling.

Foul Bore: Gun bore occupied by residual gases after firing. In small-arms weapons, a bore contaminated by excessive solid residue.

Frequency: Number of vibrations per unit time (generally, seconds).

FS: See Lacrimator.

Fulcrum: Pivot point of lever.

Fundamental: Lowest principal frequency of a sound with recognizable pitch.

Fuse: A mechanical, electrical, electronic, magnetic, or combination device used to initiate

the first element in an explosive train in a projectile at the time and under the circumstances desired. It is designed to prevent initiation at other times.

Fuze Setter: A device for adjusting time fuzes just before firing.

FXP: See NWP.

Gain: In an amplifier, ratio of output signal strength to input signal strength.

Gas Ejector: Pneumatic device that blasts air through gun bore after firing.

Gate: In radar, the movable notch, or step, used to measure the range to a target as presented on the radar range scope. When the target is gated, the radar range dial indicates the measured target range.

Gauss: Unit of magnetic field strength.

General Announcing System (1MC Circuit): Public-address system under control of OOD.

General Requirements: Requirements applicable to all Navy ordnance or other equipment. General requirements include reliability, safety, simplicity, maintainability.

Generated Target Bearing (Relative or True): The relative or true bearing of the target as determined in a computing instrument from previous positions of own ship and target and established rate of change of bearing.

Gimbal: A metal ring or similar support free to rotate on a pivot.

GP: General-purpose (bomb).

Grass: Visible "noise" in radarscope presentation.

Grid Lines (or Zones): See Military Grid Reference System.

Grid Spot Converter: Graphic computer which converts spots from observer ashore into terms usable by ship's battery.

Group Control: The control of a specified group of a battery. It is concerned with the type and method of fire control, the procedures to be employed, and the acquisition and destruction of designated targets, as well as the detection of undesignated targets appearing in the sector of fire. Group Control is exercised by the Group Control Officer, assisted by Director Officers, Mount Captains or Turret Officers, and CIC Liaison Officers.

Guided Missile: A missile whose course may be altered during flight (as by a target-seeking radar device).

Gun: Essentially, a tube closed at one end, from which a projectile is ejected by gases from a burning propellant. The term properly applies to the tube or barrel only, but is often applied to the entire mount assembly.

Gun Chase: Outer section of a gun barrel between the slide cylinder and the muzzle bell.

Gun Defense Zone: Zone about the ship to a slant range of 10,000 yards and, for the 60° cone overhead, to an altitude of 15,000 feet.

Gun Elevation: The vertical angle between the horizontal plane and the axis of the bore.

Gun Elevation Order: The signal transmitted to the gun indicating the gun elevation above the deck plane, measured in a plane through the bore axis perpendicular to the deck plane.

Gun Firing: The process of shooting a gun or guns.

- A. Gun Firing is classified as to MEANS by the firing system employed.
  1. Electric Firing provides for the shooting of a gun by an electrical system controlled by either:
     - a. Local Key provides for firing by means of a key actuated at the gun mount or turret.
     - b. Master Key provides for firing by means of a key actuated at a station remote from the mounts or turrets, such as a director or control station.
       - (1) Automatic Key is a form of master key firing in which an automatic contact maker is employed to fire at a selected firing point.
  2. Percussion Firing provides for the shooting of guns by a mechanical firing mechanism at the gun mount or turret.
- B. Gun Firing is classified as to type by the rate at which guns are shot.
  1. Rapid Fire is that type of fire in which no check fire is used for purposes of applying corrections.
  2. Slow Fire is that type of fire in which the fire is deliberately delayed to allow for the application of corrections or to conserve ammunition.
  3. Deliberate Fire is that type of slow fire which is executed on a prearranged time schedule.
- C. Gun Firing is classified as to method by the manner in which individual guns are shot with respect to the other guns of the battery.
  1. Salvo Fire is the simultaneous firing of all guns ready and aimed at the same target.
  2. Full Salvo Fire is the simultaneous firing of all guns of a group.

3. Split Salvo Fire is the firing of less than the full number of guns in a multiple gun mount or mounts at a given instant.
4. Partial Salvo Fire is the firing of less than the full number of mounts or turrets (in multiple gunmount batteries) at a given instant.
5. Continuous Fire is the firing of each gun without regard for the readiness of other guns of the battery.

Gun Housing: See Housing.

Gun Laying: The process of positioning guns in train and elevation in a predetermined relationship with respect to the line of sight. The line of sight may be established at an aloft director or generated in the plotting room, or it may be established at the gun.

A. Gun Laying is classified as to type by the manner in which guns are positioned:
   1. Continuous Gun Laying. Guns are positioned continuously in accordance with the computed signals and loaded at any position.
   2. Intermittent Gun Laying. Guns are positioned when loaded, but must be returned to a specified position after firing for loading.
B. Gun Laying is classified as to method by the means by which guns are positioned.
   1. Automatic Gun Laying. Guns are positioned automatically by remote control systems in accordance with signals received.
   2. Indicator Gun Laying. Guns are positioned locally in accordance with signals received. Positioning may be effected by either local power or manual drive.
   3. Local Gun Laying. Guns are positioned locally, by gun-sight telescope. Positioning may be effected by either local power or manual drive.

Gunnery: Operation and control of all elements of armament.

Gun Range: Range listed in the range table corresponding to gun elevation.

Gunsight Alignment: Includes those operations in battery alignment that involve the mechanical alignment of the parts making up each element—viz, alignment within each mount, turret, or gun of the battery.

Gun-Target (GT) Line: An imaginary straight line from a weapon to a target. (Same as Weapon-Target Line.)

Gun Train Order: Signal transmitted to the guns indicating the angle in the reference plane from own ship's bow clockwise to the perpendicular plane through the axis of the bore.

Guppy: A modified fleet-type submarine. Acronym from Greater Underwater Propulsion Power (project).

Gyroscope (Gyro): A device which uses the rotational inertia of a spinning wheel to establish a reference direction or plane in space, or to provide displacement in another direction proportional to any force that tends to twist the wheel's axis.

Hand Control: On certain electric-hydraulic gun mount power drives, a mechanical-hydraulic servo control by mount personnel.

Handling Room: Compartment aboard ship used for transporting and to some extent for stowage of ammunition.

Hang Fire: Accidental delayed ignition of primer, igniter, or propelling charge.

Harmonic: Any frequency higher than the fundamental of a sound; a frequency with relatively simple mathematical relationship to a fundamental frequency. Also called "partial."

Harassing Fire: Sporadic support fire designed to disturb the rest of the enemy troops, to curtail movement and, by threat of losses, to lower morale.

HBX (–1 and –3): Explosive mixtures of TNT, RDX, aluminum powder, and desensitizer.

HC: High-capacity gun projectile. Equivalent to HE in Army nomenclature.

Head (Liquid Pressure): Hydrostatic pressure.

Head (of Torpedo): See Warhead and Exercise Head.

Headlight: A light in a torpedo exercise head which is illuminated at the end of the run to assist the torpedo recovery crew to locate the torpedo.

Hedgehog: 7.2" antisubmarine warfare, ahead-thrown, short-range weapon.

Henry (h): Unit of inductance or mutual inductance.

Hertz (Hz): Term for cycles per second, used in describing frequency.

Hexogen: See RDX.

H/H: See Hedgehog.

High Explosive: Any detonating compound or mixture, such as Explosive D, TNT, RDX, HBX, etc.

Hitting Gun Range: Gun range corrected for the error of MPI.

Hitting Space: The distance measured parallel to the line of fire between a shot striking the top of the target and one striking the waterline on the engaged side of the target.

Hoisting Lug: A lug used for hoisting a bomb into aircraft. Not used for suspending the bomb in the aircraft.

Holding-Down Clips: Parts that secure base ring against being tipped out of training circle.

Homing: The final stage of a homing torpedo's run, in which it steers itself toward a target it has detected. Applied also to any target-seeking device.

Homing Torpedoes: Torpedoes with target-sensing capabilities.

Horizon Check: Comparison of elevation dial readings when battery element is laid successively on a series of points on the horizon.

Horizontal Plane: A plane tangent to the earth's surface or parallel to such a plane.

Horizontal Range: Horizontal component of slant range.

Horizontal-Type Torpedo Engine: Torpedo engine in which the turbine axis is horizontal rather than vertical (the more conventional arrangement in gas-stream torpedoes).

Housing (Gun): Chief support of recoiling gun parts; houses breech mechanism.

H-Type Torpedo Engine: See Horizontal-Type Torpedo Engine.

Hunter/Killer Force: A naval force consisting of an antisubmarine warfare carrier, associated aircraft and escorts combining specialized searching, tracking, and attacking capabilities of air and surface antisubmarine warfare units operated as a coordinated group for the conduct of offensive antisubmarine operations in an area of submarine probability.

Hunter/Killer Operations: Offensive antisubmarine operations in a submarine probability area, combining the best searching, tracking, and attacking capabilities of air, surface and subsurface units and forces in coordinated action to locate and destroy submarines at sea.

Hunting: In servosystems, a tendency for the output to oscillate because of weak signal, insufficient feedback, excessive gain, or malfunction.

HVAR: 5-inch high-velocity aircraft rocket.

Hydraulics: Study of behavior of liquids in enclosed systems. In this text, this is expanded to include the study of liquids at rest in open systems (hydrostatics).

Hydraulic Speed Gear: Combined A-end and B-end, with accessories, piping, etc.

Hydrogen Eliminator: A device on electrically driven torpedoes which is designed to dispose harmlessly of hydrogen evolved by lead-acid storage batteries. Also called a "hydrogen burner."

Hydrophone: Underwater listening device; passive sonar.

Hydrostatic Pressure: Pressure developed by weight of liquid above the point of measurement, as distinct from applied pressure transmitted through the liquid.

Hydrostatics: Behavior of liquids in open systems. Cf. Hydraulics.

Hz: Abbreviation for hertz.

IFF: Identification friend or foe—a means of challenging and identifying aircraft and ships by radar.

Igniter: Unit in a propellent train that sets off the propellant.

Illuminating Projectile: A projectile containing a chemical flare and parachute. Abbreviation: Illum.

IMP: Integrated Maintenance Plan is a part of PMS which in turn is a part of the Standard Navy Maintenance Management System.

Impact Action Fuze: A fuze that is set in action by the striking of a projectile or bomb against an object, e.g., percussion fuze, contact fuze.

Impulse Charge: A charge using black powder as a propellant: formerly used to eject depth charges and torpedoes from their launching devices.

Incident Ray: Ray (usually of light) striking a surface or boundary.

Independent Mine: Mine actuated automatically after planting and arming.

Index (of Propellant): A blend of several lots of propellant powder.

Indicator-Receiver-Regulator: (Usually abbr. to "indicator-regulator"). Controlling equipment for weapon mount power drives. Some types are called "receiver-regulators."

Indirect Fire: Support from fire delivered on a target ashore which is not itself visible from the ship, or available for use as a point of aim.

Inertia: Resistance of a mass to acceleration.

Inflammable Agent: An incendiary chemical agent, such as WP (white phosphorus).

Influence Exploder: Any type of exploder that functions when the torpedo is close to the target.

Influence Explosion: See Sympathetic Explosion.

Influence Mine: Mine that detonates when target approaches or passes near. Such mines may

have magnetic, acoustic, or pressure-sensitive mechanisms.

Inherent Corrections: Fire control problem corrections for motion of gun platform, parallax, and divergence of gun mount roller paths from deck plane.

Inhibitor: Plastic strip used to slow the burning rate of solid rocket propellant.

Initial Ballistic Correction: That part of the ballistic corrections not automatically compensated for by the fire control system.

Initial Forcing Pressure: Propellant gas pressure required to initiate movement of projectile in gun bore.

Initial Velocity (I.V.): Speed of projectile in feet per second at muzzle of gun.

Instrument Servomotors: Small fractional horsepower d-c servomotors.

Intensity Modulation: A principle of radar indicator functioning in which the electron beam is intensified to show a blip.

Intensity (of Sound Vibration): Equivalent to amplitude of vibration. (See Amplitude.)

Intensive Incendiary Bomb: Incendiary bomb using thermite.

Intercept Search: A type of passive ECM.

Intercom System: Two-way type of battle announcing system.

Interdiction Fire: Fire designed to deny the enemy ashore the use of a given route of communication, airfield, bridge, etc.

Interdirector Designation: The transmission of repeat-back information of a director to another director for the purpose of tracking the same target.

Interior Ballistics: Projectile motion and behavior while in the bore of a gun.

Internal Alignment: Adjustment of geometrical relationships within an element of a fire control or weapon system.

Jamming: Radiating interference or deceptive signals.

Jettison: To eject explosive weapons for safety reasons.

Joystick: In target designation equipment, a component used to control the output signal of dual potentiometers. These signals position designator symbols on a display and are used for transmitting target position coordinates to the converter.

Kinetic Energy: See Energy.

Lacrimator. A chemical agent that causes weeping and irritation of the throat and lungs. Example: CN (Chloracetophenone).

Ladders: A succession of salvos fired with known and predetermined changes between successive salvos, to ensure early establishment of hitting gun range and deflection in surface fire, to serve as a yardstick for covering an area target, or to increase pattern size.

A. Ladders are classified as to type by the element in which laddering takes place.
   1. Deflection Ladders are ladders fired with predetermined changes in deflection on successive salvos. They are seldom used in our Navy, except for covering area targets or in radar spotting when the discrimination of fire control radar makes a deflection rocking ladder advisable.
   2. Range Ladders are ladders fired with predetermined changes in range on successive salvos.
   3. Elevation Ladders are ladders fired with predetermined changes in elevation between successive salvos. They are seldom used in our Navy.

B. Ladders are classified as to method by the manner in which the predetermined arbitrary corrections are introduced.
   1. Initial Ladders are ladders in which, in addition to known increments or steps, the number of salvos is definitely known. This number is greater than two, and the steps are sufficiently large, so that the target will be located within the limits of the ladder.
   2. Add Ladders are fired with the initial gun range less than the best range and with successive steps of the ladder fired with increasing ranges, each increasing range spot not less than the pattern size.
   3. Drop Ladders are fired with the initial gun range greater than the best range and with successive steps of the ladder fired with decreasing ranges, each decreasing range spot not less than the pattern size.
   4. Continuous Ladders are fired with a continuous application of spots, applied in such a manner as to move the salvos back and forth across the target.
      a. Spotter-Controlled Ladder is a form of continuous ladder in which the spotter or observer determines all or part of initial direction, when to change direction, size of first ladder steps, and when the ladder is reversed. For simplicity, the size of

steps of the first ladder and successive ladders is usually prearranged. The initial correction of the first ladder may be directed by doctrine or other orders.

b. Rocking Ladder is a form of continuous ladder in which the number of steps of the ladder before reversal of direction and the size of the steps are both specified beforehand. The object is to increase the pattern size and still maintain sufficient projectile density to ensure hits. The steps of the ladder are never larger than the pattern size, and the number of steps is such as will ensure covering probable ranging and aiming errors and target maneuvers during time of flight. If used with continuous fire the steps are applied at regular predetermined time intervals; if with salvo fire, after each salvo.

Lame's Law: States relationship between tangential tension and radial pressure with variation of radius in cylinder under fluid pressure.

Land (in Rifling): High part between grooves.

Laws of Reflection:

1. Angle of incidence equals angle of reflection.
2. Normal, incident ray, and reflected ray all lie in the same plane.

Layer Depth: The depth from the surface to the top of a sharp negative gradient. Under positive gradient conditions, the layer depth is the depth of maximum temperature.

Lethal Gas: A type of poisonous chemical agent injurious when breathed or on contact. Example: Phosgene.

Level Angle: Inclination of the battery reference plane with the horizontal, measured in a plane that contains the line of sight. The latter plane may be either the vertical or a plane perpendicular to the reference plane, depending on the design of the control equipment.

Lewisite: See Vesicant.

Light Ray: An imaginary line used to show the direction in which a light wave is moving.

Limpet Mine: A mine attached by a diver to the hull of the enemy ship.

Line of Fire (LOF): The straight line joining the gun and the point of impact (or burst) of the projectile. As used in safety precautions for target practices, the line of fire is assumed to include all points near the bearing of the line of fire.

Line of Sight (LOS): Straight line joining the sight and the point of aim.

Line of Sight Coverage: The distance to which radar is limited because the radiated waves do not follow the curvature of the earth.

Liner: A cylindrical insert in the gun tube, in which (in some guns) the rifling grooves are engraved.

Loading Dead Time: The time between the instant a projectile is removed from the fuze pot and the instant of firing that projectile. For practical purposes, when firing mechanical-time-fuzed projectiles, the average loading dead time of the battery is the dead time for which correction must be made.

Loading Factor (of a Bomb): Ratio of explosive weight to total bomb weight.

Lobe: In radar, a plot of all points in the radar beam which present an equal signal from an identical target, assuming antenna bearing remains fixed.

Local Control: Control of a gun mount through signals originating at the mount.

Lock Combination Primer: A separate-loading primer that fits into a firing lock.

Lock On: Signifies that a tracking or target seeking system is continuously and automatically tracking a target in one or more coordinates (i.e. range, bearing, elevation).

Logic: As applied to electronics, the basic principles and applications of truth tables, interconnections of on-off circuit elements, and other factors involved in mathematical computations in a computer.

Logic Circuit: A computer circuit that provides the action of a logic function or logic operation. It gives a "yes" or "no" answer to a question.

Longitudinal Waves: Vibrations parallel to direction of wave front movement, causing alternate rarefactions and compressions (compression waves).

Look: In magnetic firing devices used in underwater ordnance, an actuating pulse caused by the change in earth's magnetic field resulting from movement of the firing device or a ferrous target with respect to each other.

LOS: Line of sight. (See also Sight.)

Low-Drag Bomb: An aircraft bomb streamlined for minimum drag at supersonic speed.

Lower Carriage: See Base Ring.

Low-Speed (Synchro): Synchro rotating in 1:1 ratio with input. Also called "coarse" unit.

Machine, Basic: Any device that helps to do work. There are only six basic machines: the lever, the block and tackle, the wheel and axle, the inclined plane, the screw, and the gear. Complex machines are merely combinations of two or more basic machines.

MAD (Magnetic Anomaly Detection) Equipment: Underwater target detection equipment of magnetic type carried by fixed-wing aircraft.

Magazine: Compartments aboard ship designated for ammunition stowage.

Magnetic Domain: Group of molecules that acts as a magnetic unit in a magnetic substance.

Magnetic Flux: Magnetic lines of force; magnetic field strength.

Magnetostriction: Change in shape in a metallic object caused by a magnetic field.

Maintenance and Material Management (3-M System): An integrated management system which provides for orderly scheduling and accomplishment of maintenance and for reporting and disseminating significant maintenance related information. It is composed of the Planned Maintenance Subsystem (PMS) and the Maintenance Data Collection Subsystem (MDCS).

Major Caliber (Gun): Gun of 8-inch or larger caliber.

Manual Control: Local control and positioning of a gun mount without use of power equipment.

Mass: Quantity of matter in a body.

Massing of Fire: Fire from a number of weapons, or from two or more ships, directed against a single target.

MCC: Maintenance of close contact (a type of sonar transducer coil).

MDCS: Abbreviation for Maintenance Data Collection Subsystem.

Mean Battle Range: Range at which a gun is most effective. This range is the one at which the gun sights may be boresighted.

Mean Point of Impact: The geometrical center of points of impact of all projectiles which are fired or released at the same aiming point at approximately the same time.

Merry-Go-Round:

1. Drum magazine in Mk 108 rocket launcher.
2. Rotating cage used in ammunition transfer in some 8-inch gun mounts.

Micron: 1/1000 mm.

Mil: Unit of angular measure in naval gunnery, used to specify sight deflection. One mil is the angle whose tangent is 0.001 (arc tan 1/1000), or about 0.06° (3.44'). With 6400 mils = 360°, the mil is used by ground artillery spotters to specify target bearing.

Military Grid Reference System: Method of designating areas of earth's surface by a standard pattern of perpendicular grid lines.

Military Requirements: Statement of nature and capabilities of weapon or allied equipment and systems. Capabilities are related to the purpose or task assigned to the equipment etc. in equestion.

Mine: Underwater explosive weapon actuated when approached or touched by a target.

Mine Countermeasures: All methods for preventing or reducing damage or danger to ships, personnel, aircraft, and vehicles from mines.

Mine Hunting: The branch of mine countermeasures based on determining the positions of individual mines and concentrating countermeasures on those positions, as opposed to techniques directed at a more extensive area suspected of containing mines.

Minor Caliber (Gun): Gun of caliber over 0.60 inch but under 4 inches.

Misfire: Failure of primer to ignite when firing action is initiated.

Mk (Mark): Mark (followed by a number) identifies an equipment design type. To identify a particular model, it is necessary to specify modification (mod) number in addition.

Mobile Mine: A submarine-planted, hybrid weapon combining features of an electric torpedo and a mine.

Mod: Short notation for modification.

Momentum: Tendency of a mass in motion to continue moving.

Moored Mine: A mine having a buoyant case that is held at a predetermined depth after planting by a cable or chain attached to an anchor.

Mount (Gun): The structure which supports the gun and enables it to be elevated, trained, and fired.

MTF: Mechanical time fuze.

Multi-Based Powder: Gun propellant composed chiefly of nitrocellulose, nitroguanidine, and nitroglycerine.

Multivibrator: A relaxation oscillator that uses electron tubes or transistors and other electron devices to provide a square wave output.

Mustard (Gas): See Vesicant.

Napalm: A powder employed to thicken gasoline for use in flame throwers and incendiary bombs.

Naval Gunfire Liaison Team: Personnel and equipment required to coordinate and advise ground/landing forces on gunfire employment.

Naval Gunfire Spotting Team: The unit of a shore fire control party which designates targets, controls commencement, cessation, rate and types of fire, and spots fire on the target.

Navigational Range: The best distance to the target, used in post-firing analysis.

Navol: H_2O_2 (hydrogen peroxide) in high concentration, used to supply oxygen for fuel combustion chemical torpedoes.

NavShips Technical Manual: Naval Ships Systems Command Manual. Technical compilation on shipboard equipment, some of it related to ordnance.

Navy Light: A hand-held pyrotechnic device.

Negative Buoyancy: Tendency to sink.

Negative Temperature Gradient: Density pattern in sea water tending to bend sonar sound path downward.

Neutralization Support Fire: Support Fire intended primarily to hamper or prevent enemy movement or action.

Newton's Laws of Motion:

1. A body at rest tends to remain at rest and a body in motion tends to continue moving in a straight line unless the body is acted on by some unbalanced force.
2. Acceleration of a body in response to a force is directly proportional to the force, inversely proportional to the body's mass, and in the direction of the force.
3. To each action there is an equal and opposite reaction.

Nitrocellulose: See Pyrocotton.

Nitrocotton (Nitrated Cotton): See Pyrocotton.

Noise:

1. Unorganized sounds.
2. Signals other than and interfering with the signal desired.

Nominal Initial Velocity: The initial velocity assigned a new gun with the propellant at a temperature of 90° F.

Nonautomatic (Gun): Gun in which none of the energy of the propellant is used to perform breech operations or ammunition loading or ejection.

Nonfrag: Nonfragmenting projectiles used in AA gun practice. They produce a colored smoke but no fragments when they detonate.

Nonhoming Torpedo: A torpedo without target-seeking capabilities.

Normal: Perpendicular to a surface or boundary.

Nose Cap: Armor-penetrating part of AP projectile.

Nuclear Weapon: A device in which the explosion results from the energy released by reactions involving atomic nuclei, either fission or fusion, or both.

Null: In servo terminology, equivalent to servo signal level. "Zero" implies complete absence of a signal; "null" implies no perceptible signal, although noise and other random nonsignal voltages may be present.

Nutate: To oscillate through a small angle in a specific pattern.

NWIP: See NWP.

NWP: Naval Warfare Publication. (Also called COMMTAC (COMMunications — TACtical) publications.) Any of a series of Navy publications on doctrinal and related matters. Related publications include Allied Tactical Publications (ATP's), Allied Communications Publications (ACP), Fleet Exercise Publications (FXP's), Allied Exercise Publications (AXP's), and Naval Warfare Information Publications (NWIP's).

Objective: An area or location which a troop unit is assigned to occupy or capture.

Objective (Lens): Telescope lens which forms inverted real image.

Observer-Target (OT) Line: Line joining the naval gunfire shore spotter and the target.

Ocular Lens (Telescope): Lens which makes an enlarged visual image of real image formed by objective lens.

OD: Ordnance Data — BuWeps publications containing reports of inspection and test data, primarily for use by inspectors and research personnel. ODs also contain ordnance equipment lists which provide planning information for the Bureau of Naval Weapons and the Bureau of Ships.

Offensive Minefield: Minefield laid in enemy waters to prevent movement of ships or to destroy them.

Otter: A type of underwater kite used in minesweeping.

Offset Centerline: In drydock battery alignment, a line established ashore parallel to the drydocked ship's centerline.

Ogive: Forward curved or conical part of a projectile.

Ohm's Law: Current in a circuit is directly proportional to total voltage and inversely proportional to total resistance of the circuit. $I = E/R$.

Oil Gel: Sticky combustible liquid that constitutes the active ingredient in scatter incendiary bombs.

OP: Ordnance Pamphlet—The basic BuWeps publication relating to specific ordnance equipment or data for field and fleet use.

Opportunity Fire: Fire delivered impromptu on newly discovered or transitory targets.

Optical Axis: Axis of a lens, on which light rays are not bent when entering or leaving the lens.

Ordalt: ORDnance ALTeration. A prescribed change in ordnance equipment.

Order Signal: In a servo, a control signal from outside the servo.

Ordnance: Weapons and physical equipment pertaining to them. Aboard ship it includes everything referred to as "ship's armament."

Ordnance Allowance Lists: Lists of required ordnance material for naval organizations afloat and ashore.

ORI: Operational Readiness Inspection.

Origin of Rifling (in a Gun): Where the rifling lands start, just forward of the chamber. Approximately the same location as the "forcing cone."

OT: Observer-Target line from ground observer to target ashore (used in target-grid system).

OTC: Officer in Tactical Command.

Oxidation: Combination of oxygen atoms with other atoms or atomic groups (molecules).

Parallax: The angular difference which results from making observations or computations to one target from two different stations. Train, or horizontal, parallax is the angular difference measured in the horizontal plane. Elevation, or vertical, parallax is the angular difference measured in the vertical plane.

Parallax Error (in a Telescope): Apparent target displacement when the eye is shifted about the optical axis of the eyepiece.

Partial: See Harmonic.

Pattern (of a Salvo in Range): The distance measured parallel to the line of fire, between the shot of the salvo, falling or bursting at the greatest distance from the firing point and the shot falling or bursting at the shortest distance, excluding wild shots. In deflection it is the distance measured at right angles to the line of fire between the shot falling or bursting at the greatest distance to the right and the shot falling or bursting at the greatest distance to the left, excluding wild shots.

Pattern Running (Torpedo): An alternative type of run possible with some searching torpedoes. Consists of a straight enabling run followed by a period of running continuously in circles of fixed radius.

PDF: Point Detonating Fuze.

Pellicle: A half-reflecting half-transparent optical unit.

Percussion (Fire): Firing a primer by mechanical impact.

Permeability: Ability to conduct a magnetic field.

Phase: Angular relationship between two alternating currents or voltages, e.g. between a signal voltage and a reference voltage, when the voltage or current is plotted as a function of time. When the two are in phase, the angle is zero, and both reach their peak simultaneously. When out of phase, one will lead or lag the other; at the instant when one is at its peak, the other will not be at peak value, and depending on the phase angle may differ in polarity as well as magnitude.

Phosgene: See Lethal Gas.

Pillenwerfer: Bubble-making device used by submarines to create a distracting target.

Ping: Transmitted or received sonar pulse.

"Ping" Sonar: Active sonar.

Pinger: An ultrasonic transistorized transmitting device used in locating lost drill torpedoes and mines.

Pip: Element of radar or sonar video presentation. (Preferred word is blip).

Pitch: Ship movement in response to wave motion measured in a vertical plane containing ship's centerline. In fire control, it is the instantaneous value of the angle between the reference plane and the horizontal, measured in a fore-and-aft vertical plane. Note: For purposes of naval gunnery both roll and pitch are measured and recorded as rates; that is, in terms of amplitude per unit time, ordinarily as total degrees of roll (or pitch) per minute.

Pitch (Sound): Audible quality of sound which depends on the sound's dominating frequency.

Plan Position Indicator (PPI): A CRT or screen which displays target position, director position, and designation symbols. The data appear as a result of a rotating sweep moving at a rate fast enough to prevent fading of the information. It indicates azimuth by direction of the radial line, and range by the distance of the echo signal from the center of the screen.

Planned Maintenance Subsystem (PMS): A part of the 3-M system that pertains to the planning, scheduling and management of resources (men, material, and time) to perform uniform maintenance upon equipment.

Plaster-Loaded or Sand-Loaded Ammunition: Like service ammunition but with inert load in place of burster.

Plug: See Breechblock.

Plug Gage: Instrument used to check adequacy of clearance in gun bore.

PMS: See Planned Maintenance Subsystem.

Point Fire: Support gunfire directed at a specific target for the destruction.

Point of Aim: That point on a target at which the sight is directed.

Point Oscar: Method of indirect fire.

Pointer: One who moves a weapon in elevation.

Pointing: See Elevation.

Polaris: An underwater/surface-launched, surface-to-surface, solid-propellant ballistic missile with inertial guidance and nuclear warhead.

A-1 — 1200 nautical mile range.
A-2 — 1500 nautical mile range.
A-3 — 2500 nautical mile range.

Poseidon: A ballistic missile similar to the Polaris A-3, with single or multiple target-destruction capability.

Position Angle: The vertical angle between the horizontal and the line of sight to an elevated target.

Positive Buoyancy: Tendency to float.

Potential (of a Propellant): Total work that the gases of combustion could perform while expanding from solid state to the space they would occupy when fully expanded to atmospheric pressure and cooled to a specified temperature.

Potential Energy: See Energy.

Powder Fouling: Propellant residue left in gun bore and chamber after firing.

Power: Time rate of doing work.

Prearranged or Schedule Support Fire: Gunfire formerly planned against targets at known locations.

Predicting: The process of determining future target position. Predicting operations are accomplished in computers simultaneously and automatically with tracking.

Preheater (Torpedo): Coil of tubing in turbine exhaust, used to heat air being fed to reducing valve.

Preliminary (Shore) Bombardment: Bombardment of objective area by an advance force to destroy enemy defenses.

Preparation Fire: Prearranged neutralization support fire delivered just prior to a ground attack or landing by friendly forces.

Pressure: Force per unit area.

Present Range: The best available measurement of the range to the target.

Primary Explosive: Any very sensitive explosive, such as mercury fulminate, DDNP, nitromannite, lead azide, lead styphnate, tetracene.

Prime Mover: A driving machine, such as an electric motor.

Primer: First unit in a propellant train.

Prism: Optical light-transmitting element with flat surfaces. May utilize total internal reflection.

Prismatic Sight: Any sight using prisms in the optical system.

Procedure (Naval Warfare): See Doctrine.

Programming: Setting up automatic equipment to perform operations in prescribed sequence.

Proof Run: A torpedo exercise run made before issue to the fleet.

Propellent (Adjective): Relating to or functioning as a propellant.

Propellent Train: Propellent-igniting units designed to function in sequence. Analogous to explosive train.

Propelling Charge (Propellant): Any mixture or substance that reacts or burns rapidly (usually incorporating most of its oxygen) but does not detonate, and is commonly used to propel a rocket, gun projectile, etc.

Prototype: An early (usually the first) installed model of equipment; model for later quantity production.

Proximity Fuze: A fuze designed to detonate a projectile, bomb, mine, or charge when activated by an external influence in the close vicinity of a target. The variable time fuze is one type of a proximity fuze.

PSI: Abbreviation for pounds per square inch.

Pyrocotton: Principal constituent of single-base powder. A form of nitrocellulose.

Pyrotechnics: Munitions designed to produce light or smoke for illumination or signaling.

Quality: Characteristic "color" of sound that depends on harmonic content, method of production, etc.

Radar: Radio Detection And Ranging equipment that determines the distance and usually the direction of objects by transmission and return of electromagnetic energy.

Radar Scope: CRT used as radar video display device. The following types are used:
- A Scope. An indicator with a horizontal or vertical sweep indicating range only. Signals appear as vertical or horizontal deflection on the time scale.
- B Scope. Type of presentation on which the signal appears as a bright spot with azimuth angle as the horizontal coordinate and range as the vertical coordinate.
- E Scope. A modification of the B scope. Signal appears as a bright spot with range as the horizontal coordinate and elevation as the vertical coordinate.

PPI Scope. (See Plan Position Indicator.)

Radially Expanded Gun: A type of prestressed gun barrel.

Radiofrequency (abbreviated RF or r-f): A frequency at which coherent electromagnetic radiation of energy is useful for communication purposes.

Range: Distance between two points—a station on own ship to a target or some other designated point.

Rangefinder: Optical device for measuring range to a target.

Rangekeeper: See Fire Control Computer.

Range Marks: In target designation displays, pips or traces superimposed on the video signal and supplied to a cathode ray tube at specific intervals to show calibrated range indications.

Range Rate: Rate of change of range in yards per minute caused by relative motion of own ship and target.

Range-Table Initial Velocity: The initial velocity for which the range table is computed.

Ranging: The process of establishing target distance from the firing ship.

A. Ranging is classified as to means by the instrument employed.
   1. Radar Ranging describes determination of target distance by radar.
   2. Optical Ranging describes determination of target distance by a rangefinder.
   3. Generated Ranging describes the generation of target distance by a computer.
   4. Estimate Ranging describes the determination of target distance by estimation.
   5. Navigational Ranging describes the determination of target distance by navigational means.

B. Ranging is classified as to type by the frequency with which the range is established.
   1. Continuous Ranging is that type of ranging in which target distance is continuously established.
   2. Intermittent Ranging is that type of ranging in which target distance is established at intervals.

C. Ranging is classified as to method by the procedure employed to operate the instrument.
   1. Manual Ranging is that method of ranging in which the ranging instrument is operated by hand.
   2. Aided Ranging is that method of ranging in which the generated change of range is introduced into the ranging instrument and upon which corrections are superimposed manually by the rangefinder or radar operators, as required.
   3. Automatic Ranging is that method of ranging in which the instrument automatically determines target distance of an acquired target.

Rapid Fire (RF): RF guns are those in which loading, firing, empty-case ejection, and breech operation are performed automatically by power from a source other than the propellant, and other than manual.

Rate of Climb: Rate of change of altitude measured in feet per minute or in knots.

Rate of Fire: The number of rounds fired per weapon per minute.

RDX: A high explosive. For composition, see appropriate OP. Main constituent of compositions A, B, C, Hexogen, Cyclonite.

Real Image: An optical image that exists where perceived.

Recoil: Rearward thrust on gun produced when gun fires; movement of gun parts in response to this thrust.

Recoil Mechanism: Mechanical or hydraulic brake that absorbs some of the energy of recoil.

Rectifier: A device that converts a-c volts to pulsating d-c volts. To accomplish this, a unidirectional component such as a gas tube, metallic rectifier, vacuum tube, or semiconductor diode is used.

Recuperator: See Counterrecoil.

Reduced-Pressure Air (Torpedo): Air supply at around 125 psi, used to sustain gyro spin.

Reference Plane: An arbitrarily chosen plane, usually within the ship, from which angles of elevation of all battery elements are

measured. In practice, it may be the plane containing one of the battery roller paths, or it may be an imaginary plane.

Reference Supply: A-c voltage of specified frequency and phase supplied to energize synchro and a-c servo systems. Usual reference frequencies are 60 cps and 400 cps.

Reference Voltage: Ship's a-c supply, used to energize power supplies and a-c servomotor fields.

Refraction: Bending of light or sound beam when passing through media of different density.

Refractive Index: Ratio of optical density of a light-transmitting medium to that of a vacuum.

Relative Target Bearing: The bearing of the target from the firing ship, measured in the horizontal plane from the bow of own ship clockwise from 0 degrees to 360 degrees.

Relief Valve: A valve that automatically opens to relieve excessive pressure. A safety valve is a type of relief valve.

Repeat Back: In target designation procedure, a report from director to designator affirming that target is being tracked.

Repeat-Back Knob: Visual feature of some types of TDG, used to show director position.

Repeater: Duplicate indicator.

Resistance (R): The opposition offered to current flow in a d-c circuit. In a-c circuits, resistance is the real component of impedance (the total opposition to current flow in a-c circuits).

Resistance Arm: Distance on lever arm from fulcrum to load point.

Response: In a servo, the movement effected by servo operation, or a signal based on it. This signal is fed back to the error-sensing device at the system input. Also called "feedback."

Restricted Weapons: Nuclear, biological, and chemical weapons (sometimes called NBC weapons).

Reticle: A reference mark or pattern in an optical system, visible to the user of the system.

Returnable Quota: A quota under which a crewman sent to school from a ship is returned to the ship after his training is completed.

Reverberation: In sonar, multiple echoes that tend to mask the target echo.

RF (Guns): See Rapid Fire.

Rifling: Spiral grooves in the inner surface of the gun bore.

Ring Sight: A type of nonmagnifying sight using concentric rings to aid in establishing lead angle.

Ripple Switch: A rotary multiple-contact switch used to fire a salvo of hedgehog charges in rapid succession.

Rocket: A missile not guided after launching propelled by reaction thrust evolved from burning of a fuel with oxygen supplied by the rocket.

Roll: The instantaneous value of the angle between the reference plane and the horizontal, measured in an athwartship vertical plane.

Roller Path: Roller bearing on which a weapon mount or fire control element trains.

Roller Path Compensator: A mechanical device which automatically introduces a compensating tilt at all train angles to correct for tilt of a roller path.

Roller Path Data: Tabulated measurements of inclination of a trainable battery element at various train angles.

Rotating Band: Annular part (usually of copper) on a projectile which is engraved by the gun bore's rifling when the projectile is fired.

Rotor: A part that revolves in a stationary part such as the rotating member of an electrical machine.

Run-Down Gyro: A torpedo gyroscope mechanism which coasts for the duration of the run after an initial spinning impulse.

Safety Link: Metal link designed to hold gun in battery when counterrecoil system fails or is deactivated.

Safety Valve: See Relief Valve.

SAIL: See Ship Armament Inventory List.

Salvo: One shot or several shots fired simultaneously or nearly so by the same battery at the same target.

Salvo Buzzer: A buzzer operated by the computer time-of-flight mechanism to warn of impending salvo burst or splashes.

Salvo Latch: Mechanical interlock designed to prevent accidental opening of gun breech in event of misfire or hang fire.

Sand-Loaded Ammunition: See Plaster-Loaded Ammunition.

SAP: Semi-Armor-Piercing (bomb).

SAU: In ASW, a search attack unit.

Scanning Sonar: See Azimuth Search Sonar.

SCAR: A type of 2.25-inch aircraft practice rocket.

Scatter Incendiary (Bomb): Oil-gel loaded incendiary bomb.

SC Device: A search coil used in a magnetic induction mine to detect passing ships by their distortions of the earth's magnetic field.

SCD (Sonar Display): Sonar display of PPI-type using own ship as center.

Screening Fire: Support gunfire using smoke projectiles to obstruct enemy view of friendly units and movement.

Sea Battery: An electric battery in which sea water is the electrolyte.

Seapower: "That portion of a nation's overall power which enables it to use the sea in furtherance of its interests, objectives, and policies." (NWP 10A)

Searchlight Sonar: Sonar System (now largely supplemented by azimuth sonar except for special applications) in which pulse is transmitted and received in a narrow beam.

Section: Primary organizational unit of a ship's crew.

Sectional Density: Weight of gun projectile per square inch of bore.

Sector Control: The control of one group of a battery, or two or more groups of different batteries, each of which is assigned the same sector of fire. It is concerned with the acquisition and destruction of designated targets appearing in the sector. Sector Control is exercised by the Sector Control Officer, assisted by Group Control Officers, and CIC Liaison Officers.

Sector of Fire: A specific area assigned to a unit or to a weapon to cover by fire.

Self-Destroying Fuze: A fuze designed to burst a projectile before the end of its flight.

Semiautomatic (Gun): Case gun in which some of the propellant's energy is used to open the breech, eject the empty case, and close the breech when the next round is loaded.

Semifixed Ammunition: Ammunition in which the cartridge case is not permanently attached to the projectile.

Separate-Loading Ammunition: See Bag Ammunition.

Service Ammunition: Complete ammunition assemblies fit for service.

Series Motor: An electric motor whose field winding is in series with the armature winding.

Servosystem Or Servo: Any of a variety of systems in which a relatively powerful driving unit responds to a relatively weak signal, and in which the response is fed back to the sending device at the input end of the system so that it may be compared to the incoming signal and the operation of the driving unit controlled correspondently. A "servomechanism" (also called "follow-up") is usually an electrical arrangement of this kind in which the mechanical output is produced by an electric servomotor.

Servomotor: The unit in a servosystem that drives the load, especially the electric-drive motor in a servo-mechanism or in gun elevating or training gear.

Set: Direction of ship's drift due to ocean or river current. (See also Drift (2).)

Setback: Rearward force exerted on fuze parts when projectile accelerates.

Shimming: Method of obtaining a proper level or a correct spacing tolerance by adding thin strips.

Ship Heading Line: Visual display of own-ship heading in TDS.

Ship Armament Inventory List (SAIL): A listing of all armament on a particular ship. Each ship has a SAIL tailored to its specific requirements. The SAIL also lists the status of all applicable OrdAlts.

Shore Fire Control Party: A specially trained unit for control of naval gunfire in support of troops ashore, consisting of a spotting team to adjust fire and a naval gunfire liaison team.

Sight: Optical device that establishes line of sight (LOS) to target and provides for positioning of weapon or director with respect to LOS.

Sight Angle: The vertical component of the angle between the line of sight and the axis of the bore.

Signal-To-Noise Ratio: Mathematical statement of signal strength as related to interference.

Signature: The characteristic magnetic pattern of a ship's hull as it moves past a magnetic sensing device.

Silent Running: Aboard a submarine, the state of operating in which a minimum of noise is radiated.

Simple Elevation Check: Horizon check performed at but one point on the horizon.

Single-Base Powder: Gun propellant composed of nitrocellulose, stabilizer (diphenylamine), and ether-alcohol mixture.

Single-Speed (Synchro) Operation: Use of one synchro system to transmit shaft rotation data in 1:1 ratio with original signal. Cf. Double-Speed (Synchro) Operation.

Sinking Detonator: A means of rendering a mine safe.

Slant Range: Distance to an aerial point or target.

Slide: Structural support for all parts of gun mount that move in elevation.

Slide Cylinder (of Gun): Cylindrical after part of barrel.

Slipring: Rotating annular contact.

Small Arms (Caliber): 0.60 inch or smaller.

Smokeless Powder: SPCG or single-based gun propellant.

Socket Ring: A part of an axial-piston pump which can be adjusted to regulate pump output.

Sonar: Use of sound in underwater target detection and location. (Acronym from SOund NAvigation and Ranging.) Sonar may be active (radiating pulses) or passive (listening only).

Sonar Control Indicator: Main control component in a sonar system, at which a Sonarman is stationed.

Sonar Dome: Sonar transducer housing.

Sonics: Sounds audible to the normal human ear.

Sonobuoy: Floating radio transmitter dropped from fixed-wing aircraft and fitted with underwater microphones. Used in ASW.

SPCG. A multi-base gun propellant. Also called Cordite N.

Spend Brass: Used cartridge cases.

Spigot: Part of hedgehog projector; by extension the entire hedgehog projector.

Spin-Stabilized Rocket: A rocket stabilized by rotation about its long axis.

Spiral Scan: An r-f beam which traces out a special pattern that is caused by the wobbling motion of the antenna about its axis. It is used for search and acquisition.

Spot: Correction to be applied to gun position in order to hit target.

Spot Pyramiding: Application of a new spot before effect of a previous spot has had time to become apparent.

Spotter: An observer who reports the results of naval gunfire to the firing agency and who also may designate targets.

Spotting: The estimation of the required correction of range, elevation, deflection, and fuze range to hit the target. The Spotter is the person actually observing the fall of shot or burst and making the estimates of required corrections. A Spot is the correction estimated by the Spotter.

A. Spotting is classified as to means by the station from which the observation is made:

1. Ship Spot indicates that the spotter is stationed in the firing ship at a designated spotting station.
2. Local Spot indicates that the spotter is stationed in the firing ship at or adjacent to a mount or turret.
3. Shore Spot indicates that the spotter is stationed ashore.
4. Air Spot indicates that the spotter is stationed in an aircraft or airship.

B. Spotting is classified as to type by the manner in which observations are made:

1. Visual:
   a. Eye Spotting is the term used to indicate observations made by eye without the use of optical instruments.
   b. Optical Spotting is the term used to indicate that observation is assisted by optical aids, including ordinary binoculars, spotting binoculars fitted with mil scales, spotting glasses, or stereoscopic range finders.
2. Radar:
   a. Radar Spotting is the term used to indicate that the observation is made by radar.

C. Spotting is classified as to method by the manner of estimating the error of burst or impact.

1. Direct Spotting is that method in which the spotter's correction is based on his estimate of the error of the mean point of impact from the target. A direct spot may be made on the fall of shot of one salvo or as the result of an observation of an initial ladder.
2. Bracket and Halving is a method used in visual spotting at extremely long ranges, from low spotting stations, or with poor illumination, when the spotter can determine whether the shots are short or over, but the amount of error cannot be estimated with reasonable accuracy. On observing the initial fall of shot, a spot is made which is believed to be sufficiently large to ensure crossing the target. If the next salvo crosses the target, the following spot is applied in the opposite direction (towards the target) but is half the amount of the initial spot. Successive spots are in the same direction until the target is crossed again. When this occurs, the direction of the spots is again reversed and again halved. The process is continued until the target is located within the pattern.

Squirrel-Cage Motor: A type of a-c induction motor with a cage-like conductor arrangement in the rotor.

SS: Illuminating projectile (Star Shell).

Stabilization Computer: A device that develops pitch and roll corrections for the UFCS.

Stabilization: The technique of correcting for deck inclination.

Stabilizing Generator: See Damping Generator.

Stable Element: Gyroscopic device which maintains a reference horizontal plane. Related similar device for similar purpose is called "stable vertical."

Stack: Sonar unit for producing transmitted pulse and reproducing echo.

Stand: Foundation of gun mount or missile launcher. Incorporates training circle, and is secured to ship structure.

Standard Navy Maintenance Management System: A plan of action to improve the management of maintenance and material resources in support of the Operating Forces of the Navy. (Superseded by the 3-M System.)

Star Gage: Instrument for measuring wear in gun bore.

Star Shell: See Illuminating Projectile.

Stator: A stationary part in or about which another part (the rotor) revolves, such as the stationary member of an electrical machine.

Stave: A group of magnetostrictive transducer elements arranged parallel to the long axis of a sonar transducer.

Sterilizing Device (SD): A device that automatically deactivates a mine firing system when a selected time has elapsed after placing.

Stereoscopic Rangefinder: An optical rangefinder using stereoscopic vision as its principle.

Storage Register: A register in the internal memory of a digital computer, which stores one computer word.

Straddle: This is obtained from a salvo in range (or deflection) when, excluding wild shots, a portion of the shots of that salvo fall or detonate short and other shots of the salvo beyond the target (right and left, respectively, for deflection). (In naval gunfire support this may be known as a Bracketing Salvo.)

Striker: A serrated rim training for a rating.

Subroc: SUBmarine ROCket. Submerged, submarine-launched, surface-to-surface rocket with nuclear depth charge or homing torpedo payload, primarily anti-submarine.

Subsonics: Sounds below audible range.

Superelevation: The angle the gun must be elevated above the line of sight to compensate for the curvature of the trajectory caused by the force of gravity acting on the projectile.

Superheater (Torpedo): See Combustion Flask.

Supervisory Control: The direction of the overall employment of the ship's armament. It is concerned with the disposition of the batteries to best meet existing conditions, the interior communications plan to be used, the selection and designation of targets for batteries or groups thereof, and the designation of standard procedure to be employed. Supervisory control is exercised by the Weapons Officer, assisted by his Battery Officers, and by CIC Liaison Officers.

Support Fire: Fire directed by ships or other afloat units at targets ashore, usually in support of ground troops operations.

Surface Burst: An explosion of a nuclear bomb or projectile at the surface of the earth; also the explosion of a nuclear weapon at an elevation above ground such that the fireball touches the ground.

Suspension Lug: A lug used for supporting a bomb in its aircraft.

Swim-Out: An alternate method of launching torpedoes, in which the torpedo propels itself out of an underwater tube instead of being ejected.

Sympathetic Explosion: Detonation of an explosive mass by shock wave of another detonation in the vicinity.

Synchro: Any of five types of rotatable induction devices that can produce a unique voltage pattern corresponding to any shaft position, or reproduce the shaft position from the pattern, or control a servo to do this. They are used in data transmission systems and as computing devices.

Synchronous Motor: An a-c motor designed to operate "in step" with the a-c supply; hence it has a constant-speed characteristic limited in accuracy only by the steadiness of the supply frequency.

System Alignment: Adjustment of geometrical relationship between two or more major components of a weapon system.

Talos: A shipborne, surface-to-air missile with solid-propellant rocket/ramjet engine. It is equipped with a nuclear or nonnuclear warhead, and command, beam-rider homing guidance.

Target-Grid System: Method utilizing a grid spot converter device to make spots observed by ground parties available without delay to ship fire control systems.

Tartar: A shipborne, surface-to-air missile with solid-propellant rocket engine and nonnuclear warhead.

Tachometer Generator: A generator whose voltage output is directly and precisely proportional to its rate of rotation. Frequently used as a Damping Generator.

Tail (of Torpedo): Aftermost part of a torpedo. Carries propellers and control surfaces.

Talker: Enlisted man assigned to man a battle phone for an officer at a control station.

Tampion: Plug inserted in gun muzzle to protect bore.

Target Acquisition: The process of positioning the tracking apparatus of a control system so that a designated target is gated in the radar or fixed in the optics or open sights.

Target Angle: The relative bearing of own ship from the target, measured in the horizontal from the bow of the target clockwise from 0° to 360°.

Target Designation: The selection of the targets which are to be taken under fire, and transmission of the requisite information for acquisition to the selected fire control station or stations.

A. Target Designation is classified as to type by the station originating the designation.
   1. Command Designation is the designation of a target by a command station.
      a. OTC designating a ship to take target under fire.
      b. CO of a ship designating target to be taken under fire.
   2. Control Designation is the designation of a target from a fire control station.
   3. Local Designation is the designation of a target by mount or turret personnel.

B. Target Designation is classified as to method by the procedure employed for designation.
   1. Automatic Designation is the designation of the target by means of instruments which transmit sufficient data to the selected gun fire control system to result in target acquisition.
   2. Partial Automatic Designation is the designation of the target by means of a partially automatic system which must be aided by coaching in order that the selected director will be positioned to acquire the target.
   3. Verbal Designation is the designation of the target by voice or telephone.

Target Evaluation: Estimates of target intent, degree of threat, and type of attack to be delivered, based on plots of a target position.

Target Indication: A manifestation, to command and control, of targets approaching into or appearing in the area of gunfire. It includes all information available for proper designation, including the presence, identity, location, size, number, course, speed, and estimate of intent, plus any additional evaluated factors which are necessary for proper designation.

A. Target Indication is classified as to type by the means by which target presence is manifested.
   1. Radar Indication describes manifestation of target presence by radar.
   2. Visual Indication describes manifestation of target presence by visual sighting.

B. Target Indication is classified as to method by the system employed to display target presence.
   1. Automatic Indication is indication of targets by means of an electromechanical system capable of indicating in one display all targets appearing in the area under investigation.
   2. Manual Indication is the indication of targets by means of a manual plot of all targets observed or reported in the area under investigation.

Target (Projectile): See BL.

TCD (Sonar Display): Sonar display of PPI type using target as center.

TDS: Target Designation System.

TDT: Target Designation Transmitter.

Temperature Inversion (in Sea Water): A cooler layer of water overlying a warmer one.

Terrier: A surface-to-air missile with solid-fuel rocket motor. It is equipped with radar beam rider or homing guidance and nuclear or nonnuclear warhead.

Test Depth: Maximum depth for a submarine or underwater weapon.

Tetrode: An electron tube containing four elements (electrodes)—plate (anode), cathode, control grid, and (usually) a suppressor grid.

Tetryl: An aniline-based organic compound used as a high explosive.

TH: See Thermite.

Thermite (or Thermate): A mixture of iron oxide and aluminum, often used as a filler in incendiary bombs.

Thermocline: Layer of sea water in which density changes rapidly with depth.

Theta (θ): Greek letter used to designate a selected angle.

Thrown Weapons: Small contact or proximity fuzed ASW explosive devices thrown by a rocket or mortar device from attacking surface ship.

Thyratron: A special type of high-output gas-filled electronic tube.

Time Base: Length of full-width sweep (A-scope radar presentation).

Time Fuze: A fuze which contains a graduated time element to regulate the time interval after which the fuze will function.

Time of Flight: Time elapsed from projectile's firing till its impact or explosion.

TNT: Trinitrotoluene. A high explosive.

Torch Pot: In a torpedo exercise head, the torch pot gives off smoke to assist the torpedo recovery crew to recover the torpedo at the end of a run.

Torpedo: A self-propelled underwater weapon whose explosive warhead is detonated upon contact with or in proximity to a waterborne or subsurface target. A torpedo may be a component of a more complex weapon, for which it serves as the terminal stage. (Examples: Astor, Subroc, Dash.)

Torpedo Mines: See Mobile Mines.

Torpedo Tube: A torpedo launching device tubular in configuration, from which the torpedo is normally ejected by compressed air.

Torque: Twisting effort, expressed in pound-feet.

Torque Motor: A motor whose armature movement is restricted to less than one revolution, and whose output is a torque proportional to its input.

Total Internal Reflection: See Critical Angle.

Tq: Underwater fire control symbol for dead time.

Tracer: Pyrotechnic device on projectile which shows projectile track when in flight.

Tracking: The process of establishing the path of target motion with respect to the firing ship; it is accomplished by combining the data obtained by the aiming and ranging processes.

A. Tracking is classified as to type by the form of tracking employed.

1. Direct Tracking is that type of tracking in which target path is established by direct observation (radar, optical or sonar).
2. Indirect Tracking is that type of tracking in which the range, bearing, and elevation of the target are generated by the computer and its associated equipment.
3. Offset Tracking is that type of tracking in which the target path is established by the direct observation of an intermediate point of aim in known relationship to the designated target.

B. Tracking is classified as to method by the manner in which the computers are employed to determine the path of target motion.

1. Automatic Tracking is that method of tracking in which the target path is established by use of radar for aiming and ranging and without manual operation of any of the tracking controls in the fire control system.
2. Automatic Lead Computing is that method of tracking in which the process of aiming automatically generates a solution of target motion. This method of tracking is associated with instruments using gyros to measure the angular velocity of the LOS.
3. Rate Control is that method of tracking in which the computer's generated path of estimated target motion is made to coincide with the observed path of target motion by comparing the observed and generated rates of motion.
   a. Automatic Rate Control is that method of rate controlling in which the generated target motion is automatically corrected to agree with the observed target motion by a rate-control mechanism operated by the director operators.
   b. Semiautomatic Rate Control is that method of rate controlling in which the generated target motion is automatically corrected to agree with the observed target motion by a rate control mechanism operated by the computer operators.
   c. Manual Rate Control is that method of rate controlling in which the generated target motion is corrected to agree with observed target motion by changes to target course, speed, and angle of climb introduced manually by the computer operators.

Train: The movement in the horizontal plane of a gun mount or launching equipment.

Train Alignment: Alignment of fire control and weapon systems elements so that they are in effect all parallel and all at exactly the same angle to a selected vertical plane.

Trainer: One who moves a weapon in azimuth.

Training Circle: A large circular gear at the base of trainable weapon equipment.

Training Gear: Mechanical, electrical, and hydraulic equipment used to move weapon equipment in azimuth.

Tramming: Procedure for verifying train and elevation dial accuracy on gun mounts.

Transducer (Sonar): Device that translates sound waves into electrical signals, and vice versa.

Transistor: An active semiconductor device having three or more electrodes (elements). Transistors can perform almost all the functions of electron tubes.

Transmission Check: In fire control system alignment, the process of verifying that the data transmission system is functioning with the accuracy required.

Transmission Loss: Signal strength lost in transmission.

Transverse Waves: Vibration at right angles to direction of wave front movement.

Traverse Plane: A plane determined by a point of aim and the elevation axis of the sight.

Trench-Warfare Ammunition: Ammunition for certain types of infantry weapons.

Triode: A three-electrode electron tube. It has a plate (anode), cathode, and control grid.

Triple-Based Powder: See Multi-Based Powder.

Tilt Box: A part of an axial-piston pump containing the socket ring.

Tritonal: A mixture of TNT and aluminum powder.

True Target Bearing: True bearing of the target from the firing ship.

True Wind: Wind as it exists with respect to the earth and independent of any motion of the ship.

Trunnions: Part of the gun mount slide. The center of rotation in elevation movement.

Trunnion Tilt: Instantaneous inclination of the axis of the trunnions to the horizontal.

Truth Table: A table that describes a logic function by listing all possible combinations of input values and indicating for each combination the true output values.

Tud: In underwater fire control, symbol for time to fire.

UB Plot: Underwater Battery Plot.

UFCS: Underwater Fire Control System.

Ultrasonics: Sound above normal human audible frequency range. Usual upper limit of audibility is taken to be about 15 kHz (15,000 Hz) ("Supersonics" used in this sense is no longer correct.)

Underwater Demolition: The destruction or neutralization of underwater obstacles, this is normally accomplished by underwater demolition teams.

Unit Replacement Principle: Replacement of complete subassemblies by others in event of failure in the field, instead of replacement of failed or defective components only.

Universal Motor: A motor (usually fractional horsepower) that can be operated on either a-c or d-c.

Upper Carriage: The part of the gun mount rotating structure that contains the trunnion bearings.

UPS: Universal Polar Stereographic (military grid system).

Urgent Attack (ASW): Attack on submarine which is in position to fire torpedoes.

USNMI: U.S. Navy Maneuvering Instructions.

UTM: Universal Transverse Mercator (military grid system).

Vacuum Tube: See Electron Tube.

Variable Time Fuze: A fuze designed to detonate a projectile, bomb, mine, or depth charge when activated by external influence other than contact in the close vicinity of a target.

VDS: Variable Depth Sonar. A device on the fantail of a destroyer to lower a sonar transducer to a variable depth to search below the layer depth.

Vehicle: The carrier or delivery device in a weapon system.

Vertical Plane: A plane perpendicular to the horizontal. It may pass through any designated line or point.

Very Light: A projected pyrotechnic device.

Vesicant: A chemical agent that blisters the skin, such as lewisite and mustard.

Video: Visual signal presentation, or electrical signal which eventually forms a part of a video presentation.

Virtual Image: An optical image that does not actually exist at the location where it appears to be.

Voltage Regulator: A device that maintains the voltage of a voltage source essentially constant regardless of variations in input voltage and load.

VT: Proximity (fuze).

Wander Marks: Reticle marks used in stereoscopic rangefinder.

Warhead: 1. That part of a missile, projectile, or torpedo that constitutes the explosive, chemical, or other charge intended to damage the enemy. 2. A major assembly, which includes either the nuclear or thermonuclear system, high explosive system, chemical and biological agents or inert materials.

Warhead Section: A completely assembled warhead including appropriate skin sections and related components.

Watch, Quarter, and Station Bill (WQ & S Bill): A chart showing for each billet the name and rate assigned, cleaning and maintenance station, and assignments in condition watches and specific bills.

Waveguide: Radar wave conductor.

WDE: Weapons Direction Equipment. It usually consists of one or more Target Selection and Tracking Consoles, a Director Assignment Console, a Weapon Assignment Console, and the necessary cabinets to house power supplies and computer units.

WDS: Weapons Direction System. It is made up of WDE and units that support its function.

Weapon: The destructive unit in a weapon system. Except for guns, the weapon is the unit that actually destroys the target (commonly by explosion).

Weapon System: The combination of a weapon (or multiple of weapons) and the equipment used to bring the destructive power of the weapon against the enemy. It includes units to —

1. Detect, locate, identify the target.
2. Deliver or start delivery of weapon to target.
3. Control delivery unit or weapon.
4. Destroy the target (weapons).

Weapons Doctrine: General instructions on course of action to be taken by officers supervising weapon operations in specific tactical situations.

Wear Gage: Instrument for measuring erosion at origin of rifling in minor caliber guns.

Weight: Amount of gravitational pull on a body.

Wild Shot: A shot with an abnormally large dispersion in range, or in deflection, or in both.

Wind Direction: Direction from which the wind is blowing.

Window: Projectile that ejects foil strips to make a deceptive radar target or screen.

Windshield: Thin metal fairing over nose of AP projectile.

WLO: Weapons Liaison Officer. The weapons department representative in CIC.

Work: Force acting against a resistance through a distance, resulting in movement of a load against a resistance, or acceleration of a mass.

Working Pressure Air: In a torpedo, compressed air at a pressure around 500 psi.

WP: White phosphorus.

Yoke (Gun): In bag guns, the equivalent of the gun housing.

Zero Length Rocket Launcher: A rocket launcher (used today only in aircraft) which does not support the rocket after the burning propellant has begun to move the rocket.

Zone of Responsibility: A predetermined area of enemy terrain which supporting ships are responsible for covering by fire on known targets or targets of opportunity and by observation.

Zuni: An air-to-surface unguided rocket with solid propellant. Can be armed with various types of heads, including flares, fragmentation, and armor piercing.

PART 2—GLOSSARY OF FIRE CONTROL SYMBOLS

This is a special glossary designed for the convenience of those desiring to understand the derivation of fire control symbols or to know the meaning of specific symbols used in AA and surface gunnery. It does not include all of the symbol variations used in AA and surface gunnery, nor does it cover symbols used in underwater fire control or in guided missile fire control. For detailed authoritative treatment, refer to OP 1700, which, in its three volumes, explains all fire control values, their symbols, and their derivation.

Symbols are used in fire control to provide a concise way to represent values which otherwise would require extended definition. Fire control symbols are made up of capital letters standing for basic quantities; and lower case letters, arabic numerals, and the prime (') are used as modifying symbols. For example, "So" is made up of a basic symbol "S" meaning "speed" and a modifying symbol "o" meaning "of own ship." Hence, the symbol So signifies own ship speed. The prime (') before a quantity denotes measurement from a normal plane. After a quantity, it denotes measurement to or in a normal plane (a plane perpendicular to the deck). (Bear in mind that some publications still may be using the old fire control symbols, the ones that are used in this book's predecessor.)

BASIC SYMBOLS AND DEFINITIONS

Symbol	Definition
A	Angular movement in elevation.
B	Bearing (of target, unless modified) measured in the horizontal plane.
C	Course, measured in the horizontal plane.
D	Rate of
E	Elevation (of target, unless modified) measured in the vertical plane.
El	Level angle.
Eu	Angle of depression (pertaining to the line of sound).
F	Missile offset angle.
G	Gyro angle.
H	Distance (between two points).
I	Angle of inclination (useful only as a rate).
L	Sight deflection; total lead angle between line of sight and line of fire.
M	Linear movement.
P	Gun parallax displacement.
Pn	Director parallax base length.
R	Range.
S	Lateral angular movement.
T	Time.
U	Velocity.
V	Sight angle.
W	Wind rate.
Y	Radius of turn.
Z	Crosslevel angle.

COMMON BASIC SYMBOL-MODIFIERS AND DEFINITIONS

Symbol	Definition
a	Apparent; expressing rates and angles of apparent wind.
b	Bearing.
d	Deck; quantities measured in, from, or about axes in the deck plane.
e	Elevation.
g	Gun.
h	Horizontal.
k	Earth; quantities expressing earth's rate.
o	Own ship.
p	Prediction.
q	Heading; the compass head of own ship or target.
r	Range.
s	Line of sight.
t	Target.
v	Vertical.
w	Wind; of or due to wind.
x	East-West measurement.
y	North-South measurement.
z	Of or due to cross level.
'	Prime (before quantity); measurement from a normal plane.
'	Prime (after quantity); measurement to or in a normal plane.
''	Double prime (before quantity); measurement from a plane normal to the slant plane.
''	Double prime (after quantity); measurement to or in a plane normal to the slant plane.
1	Present position.
2	Future position.
3	Advance position.
4	Aiming position.
5	Fuze computation quantities.

QUANTITY MODIFIERS

(These modifiers are used before or after parentheses.)

Modifier	Name	Before The Parenthesis	After The Parenthesis (NM denotes no meaning)
a	Advance	Portion of quantity measured to advance position	NM
b	Ballistics	Superelevation or drift	Superelevation or drift correction
c	Computed or Generated	Value of quantity computed or generated in mechanism	NM
d	Designated	Designated value of quantity	NM
e	Estimated or Error	Estimated value or error	NM
f	Function	Function of a quantity	NM
g	Dead Time	Correction due to dead time	The quantity corrected for the effect of dead time
i	Increment	An increment of a quantity	NM
j	Computational Addition or Partial	A computational addition to the quantity	A partial value of the quantity
k	Earth	NM	Referred to earth frame
l	Initial	The initial value of the quantity	NM
m	Relative Motion	The portion of the quantity accounting for relative motion between own ship and target	The quantity corrected for the effect of relative motion between own ship and target
o	Observed or Measured	Observed or measured value of a quantity	Referred to a frame rigidly attached to own ship
p	Gun Parallax	Portion of quantity accounting for gun parallax	Quantity corrected for the effect of gun parallax
pc	Director Parallax	Director parallax portion of quantity	Director parallax correction
q	Corrective Input or Spot	Corrective Input or Spot	NM
r	Rate Control	Rate control correction to a quantity	The quantity including the rate control correction
s	Selected	Selected value	Referred to inertial frame
u	Initial Velocity Loss	Portion accounting for change in initial velocity	Corrected for change in initial velocity
w	Wind	Effect of wind	Correction for effect of wind

PRINCIPAL FIRE CONTROL QUANTITIES
(Selected items only are listed.)

A . . . . Relative angular movement in elevation. The difference in elevation from the horizontal plane between the present line of sight and line to the future target position, measured upward to the line to future target position in a vertical plane. (Symbol was previously used for target angle.)

B . . . . Relative target bearing. The angle between the vertical plane through own ship centerline and the vertical plane through the line of sight, measured in the horizontal plane clockwise from the bow of own ship. (Previously called Br.)

Bd . . . . Director train (stabilized sight). Angle between the vertical plane through own ship centerline and the vertical plane through the line of sight, measured in the deck plane clockwise from the bow of own ship. (Previously called B'r.)

Bd'. . . . Director train (sight not stabilized). Angle between the vertical plane through own ship centerline and the normal plane through the line of sight, measured in the deck plane. Positive angles are measured clockwise from own ship centerline. (Previously called B'r'.)

Bog . . . Gun parallax angle. Angle between normal plane through reference line and normal plane through gun parallax base line, measured in the deck plane clockwise from reference line.

Boe . . . Gun parallax angle. Angle between normal plane through reference line and normal plane through director parallax base line, measured in the deck plane clockwise from reference line.

Bot. . . . Target angle. Angle between vertical plane through the relative target speed vector and the vertical plane through the line of sight, measured in the horizontal plane clockwise from the target speed vector. (Previously called A.)

Bwy . . . True direction true wind. Angle between the north-south vertical plane and the vertical plane through the direction from which the true wind is blowing, measured in the horizontal plane. Positive angles are measured clockwise from North. (Previously called Bw.)

By . . . . True target bearing. Angle between the north-south vertical plane through the line of sight, measured in the horizontal plane. Positive angles are measured clockwise from North.

c(B) . . . Generated relative bearing. (See definition of B.)

c(E) . . . Generated target elevation. (See definition of E.)

Co . . . . Own ship course. Angle between the north-south vertical plane and the vertical plane through own ship centerline, measured in the horizontal plane. Positive angles are measured clockwise from North.

Cgo . . . Own ship heading. Angle between the North-South vertical plane and the vertical plane through own ship centerline, measured in the horizontal plane. Positive angles are measured clockwise from North.

Cgt. . . . Target heading. Angle between the North-South vertical plane, and the vertical plane through the target centerline, measured in the horizontal plane. Positive angles are measured clockwise from North.

Ct . . . . Target course. Angle between the North-South vertical plane, and the vertical plane through the target speed vector (referred to the frame used by the fire control system), measured in the horizontal plane. Positive angle is measured clockwise from North.

Cw . . . . True course true wind. Angle between the North-South vertical plane, and the vertical plane through the direction toward which the true wind is blowing, measured in the horizontal plane. Positive angles are measured clockwise from North.

DBs . . . Angular bearing rate in slant plane. The angular rate of the line of sight in the slant plane through the line of sight and through the director elevation axis in the horizontal plane, measured with respect to the initial position of the line of sight at the instant of firing. The initial position of the line of sight is fixed in the reference frame used by the fire

control system to measure the angular rate.

DE . . . . Angular elevation rate. The angular rate of the line of sight in the vertical plane through the line of sight, measured with respect to the intersection of the vertical plane through the line of sight and the horizontal plane. (Previously called dE.)

E . . . . Target elevation. Angle between the horizontal plane and the line of sight, measured in the vertical plane through the line of sight. Positive angles are measured upward from the horizontal plane.

E' . . . . Target elevation. Angle between the horizontal plane and the line of sight, measured in the normal plane through the line of sight. Positive angles are measured upward from the horizontal plane.

Ed . . . . Director elevation. Angle between the deck plane and the line of sight, measured in the vertical plane through the line of sight. Positive angles are measured upward from the deck plane.

Edg . . . Gun elevation order. Angle between the deck plane and the line of fire, measured in the vertical plane through the line of fire. Positive angles are measured upward from the deck plane.

Edg' . . . Gun elevation order. Angle between the deck plane and the line of fire, measured in the normal plane through the line of fire. Positive angles are measured upward from the deck plane. (Previously called E'g.)

Eg . . . . Gun elevation. Angle between the horizontal plane and the line of fire, measured in the vertical plane through the line of fire. Positive angles are measured upward from the horizontal plane.

El . . . . Level angle. Angle between the horizontal plane and the deck plane, measured in the vertical plane through the line of sight. Positive angles are measured downward from the horizontal plane on the target side of own ship. (Previously called L.)

Eb . . . . Pitch. Angle between the horizontal plane and the deck plane, measured in the vertical plane through own ship centerline. Positive angles are measured downward from the horizontal plane.

E2 . . . . Future target elevation. Angle between the horizontal plane and the line to the future target position, measured in the vertical plane through the line to the future target position. Positive angles are measured upward from the horizontal plane.

L . . . . . Total lead angle. Angle between the line of sight and the line of fire.

Ld . . . . Deck deflection. Angle between the vertical plane through the line of sight, and the vertical plane through the line of fire, measured in the deck plane from the vertical plane through the line of sight. (Previously called Dd.)

Lh . . . . Horizontal deflection. Angle between the vertical plane through the line of sight and the vertical plane through the line of fire, measured in the horizontal plane from the vertical plane through the line of sight. (Previously called Dh.)

Ls . . . . Sight deflection. Angle between the line of sight and the vertical plane through the line of fire, measured from the line of sight in the slant plane through the line of sight and through the director elevation axis in the horizontal plane. (Previously called Ds.)

Lz . . . . Trunnion tilt correction. Correction to gun train order for the tilting of the gun trunnions due to crosslevel. (Previously called Dz.)

M . . . . Total relative movement. Total linear displacement of the target during the time of flight due to relative motion between own ship and target in the frame used by the fire control system.

Mh . . . . Linear movement in horizontal. The linear displacement during the time of flight in the horizontal plane and in the vertical plane through the relative target speed vector in the frame used by the fire control system. Modifier o is added (Mho) to express the quantity due to own ship motion, and modifier t is added (Mht) to express the quantity due to target motion.

Mr . . . . Linear movement in range. The linear movement during time of flight along the line of sight, due to relative motion between own ship and target in the frame used by the fire control system.

P. . . . . Gun parallax base length. Total distance from the reference point to the gun, measured along the gun parallax base line.

Pd . . . . Director parallax base length. The total distance from the reference point to the director, measured along the director parallax base line.

R. . . . . Present range. Distance from own ship to target, measured along the line of sight.

Rh . . . . Horizontal range. Projection of present range in the horizontal plane by a vertical plane through the line of sight.

Rv . . . . Target height. Height of target above the horizontal plane, measured in the vertical plane through the line of sight.

R2 . . . . Future range. The distance from own ship to future target position, measured along the line to the future target position.

R3 . . . . Advance range. Distance from own ship to the advance target position. (Previously called R2.)

R4 . . . . Aiming range. The distance from own ship to the aiming position, measured along the line of fire.

R5 . . . . Fuze range. Range used in the computation of fuze setting order. It is equal to advance range plus change in range during dead time.

S. . . . . Total angular movement. The total angle between the line of sight and the line to the future target position.

Sh . . . . Horizontal angular movement. Angle between the vertical plane through the line of sight and the vertical plane through the line to future target position, measured in the horizontal plane from the vertical plane through the line of sight.

T. . . . . Clock time.

Tg . . . . Dead time. Time between setting the fuze and firing the shell (projectile) or time for which computational quantities must be modified when launching (missiles) is delayed.

U. . . . . Initial velocity. The velocity of the projectile with respect to the gun muzzle at the instant the projectile leaves the gun.

Vs . . . . Sight angle. Angle between the line of fire and the slant plane through the line of sight and through the director elevation axis in the horizontal plane, measured from the line of fire in the vertical plane through the line of fire.

Vz . . . . Trunnion tilt correction. The part of gun elevation order accounting for the tilting of the gun trunnions due to crosslevel.

W . . . . True wind speed. The total rate of the true wind measured with respect to the earth.

Zd . . . . Crosslevel. Angle between the vertical plane through the line of sight and the normal plane through the intersection of the vertical plane through the line of sight and the deck plane measured about the axis which is the intersection of the vertical plane through the line of sight and the deck plane.

Zs . . . . Angle between the vertical plane through the line of sight and the normal plane through the line of sight, measured about the line of sight as the axis.

APPENDIX II

BALLISTIC CALCULATIONS

This appendix is divided into two main sections. The first section explains the uses of range tables, and the second section gives instructions for using the air-density nomogram.

This discussion is based on information about a 5"/38 gun and its projectile, contained in OP 551, third revision. Ballistic information on projectiles for other guns may be found in the appropriate OP range table (as this information is called). For example, the range table for certain 5"/54 gun projectiles is found in OP 1152.

USES OF RANGE TABLES

The range table is published by the Naval Ordnance Systems Command for each gun and for each projectile type fired by the gun. It presents, in convenient form, the elements of the trajectories resulting from firing that specified projectile, at a specified initial velocity, at various angles of elevation, under standard conditions. A range table tabulates, for each 100-yard increment of range, such characteristics of the trajectory as angle of elevation, time of flight, angle of fall, and striking velocity.

Preparation of a range table involves experimental firings of a number of the specified projectiles to obtain data used in conjunction with a complex set of equations or formulas to solve the trajectory.

Normal practice at the Naval Ordnance Laboratory is to compute all range table entries directly from equations by means of large mechanical and electronic computing machines. These machines are capable of handling a large number of complex solutions rapidly and accurately.

STANDARD CONDITIONS FOR RANGE TABLES

In the computations upon which range tables are based, certain arbitrary conditions are assumed. These are range-table standard conditions. To use the range table under conditions other than standard, it is necessary to provide in the table corrections for variations from these conditions.

The standard conditions assumed for range-table values are that:

1. The projectile leaves the gun with the designed velocity.
2. The projectile is of the designed weight.
3. The atmosphere is of an arbitrarily chosen standard density.
4. There is no wind.
5. The gun is motionless.
6. The target is motionless.[1]
7. The earth is motionless.
8. The gun and target are in the same horizontal plane, the plane tangent to the earth's surface at the gun.
9. The gun is elevated in the vertical plane; that is, the axis of the gun trunnions is horizontal at the time of firing.

Variations from any one of these conditions may cause a significant error. Therefore, in addition to the tabulation of trajectories under standard conditions, the range table provides necessary corrections for variations from the first six of these standard conditions. Corrections for variations from any of the last three require separate consideration or computation.

Correction for rotation of the earth can be computed from auxiliary tables published with range tables for major-caliber guns, or by fire control instruments. The amount and direction of error vary with the azimuth of the line of fire, the latitude, and the range; but remain small in all cases. The correction is disregarded for guns of 5-inch caliber or smaller. The correction for tilt of the trunnion axis from the

[1]Although motion of the target does not affect the trajectory itself, it enters into the problem of determining the trajectory that will reach the target.

horizontal is practical only when using a mechanical solution and is considered in the fire control problem. Use of the columns of the range table to account for nonstandard conditions will be taken up later.

A TYPICAL RANGE TABLE

The discussion which follows is based on the range table (OP551, third Revision) for the 5"/38 gun using a 55.18-pound AA common projectile. The table, excerpts of which are shown in figure A2-1, is based on an I.V. of 2500 ft. per second — an average value for 5"/38 guns.

Columns 1 to 8 inclusive give values of elements of the trajectory under standard conditions corresponding to a given range, in increments of 100 yards.

Columns 10 to 18 inclusive (there is no column 9) list errors caused by the fact that actual firing is seldom, if ever, conducted under actual range table conditions. The heading over each column indicates both cause and direction of error.

COLUMN 10

Column 10 is headed "Change in range for 10 F.S. increase in initial velocity." The two major elements which affect initial velocity are gun erosion and variation in powder temperature. Of these, erosion causes a loss in initial velocity and a decrease in range. The Navy range tables are based on a standard powder temperature of 90° Fahrenheit. Magazine temperature rarely exceeds this figure. The variation in velocity due to temperature variation of one degree from 90° F. is stated in certain range tables and other NavOrdSysCom publications. The loss of initial velocity per degree of change of powder temperature will vary with the caliber, powder index (i.e., manufacturing lot), and erosion.

The loss of velocity caused by erosion is dependent upon the amount of bore enlargement. The range table includes one table which shows the amount of velocity loss for specified amounts of bore enlargement, which can be used following star gaging, and a second table showing bore enlargement versus equivalent service rounds fired, for use in periods between star gaging.

It must be noted that initial velocity for a new 5"/38 gun is 2600 ft. per sec. (often abbreviated also as f.s. or f.p.s.). Since the average velocity during the life of the gun is 2500 ft. per sec (the range table's assumed value), in a relatively new gun, velocity change due to bore enlargement may have to be computed in relation to the range table as a gain rather than a loss.

COLUMN 11

Column 11 is headed "Change in range for 1 pound decrease in projectile weight." This change of range is due to two causes which are opposite in their effects. The first is the change in I.V. A projectile heavier than standard will be expelled from the gun at lower than designed I.V., causing a decrease in range. However, increase in weight will cause an increase in momentum, which results in an increase in range.

In practice, column 11 is not normally used aboard ship, since only projectiles of standard weight are fired. Projectiles are required to be of designed weight within small tolerances. The effects of these small variations are neglected. This small variation in projectile weight is one reason why all shots of a salvo, fired at the same time and under the same conditions, do not fall at the same point.

COLUMN 12

Column 12 is headed "Change in range for 10 percent decrease in air density." For use under conditions where no aloft observations of air density are possible, a table has been prepared based on the results of many past observations aloft. The entering arguments are the height of the maximum ordinate in feet and the surface density; the result is the ballistic density. Standard surface density has been arbitrarily selected as the density of the atmosphere at a temperature of 59° F., a barometric pressure of 29.53 inches of mercury, and a humidity of 78 percent saturation. This standard surface density is assigned a numerical value of 1.000. To determine variation in the trajectory caused by variation from standard surface density, the temperature and barometric pressure are measured at the surface and the resulting density is expressed as a percentage of the standard. This percentage of standard density at the surface is then used in the table of ballistic density and from it the ballistic density is found.

[illegible]

RANGE	ANGLE OF ELEVATION			CHANGE IN ANGLE OF ELEVATION FOR 100 YDS. INCREASE IN RANGE	ANGLE OF FALL		TIME OF FLIGHT	STRIKING VELOCITY	DRIFT	DANGER SPACE FOR A TARGET 20 FT. HIGH	MAXIMUM ORDINATE
1 YARDS	2 DEG.	MIN.	2A MINUTES	2B MINUTES	3 DEG.	MIN.	4 SECONDS	5 FT./SEC.	6 YARDS	7 YARDS	8 FEET
8000	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8100	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8200	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8300	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8400	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8500	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8600	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8700	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8800	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8900	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9000	8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9100	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9200	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9300	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9400	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9500	9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9600	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9700	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9800	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9900	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10000	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10100	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10200	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10300	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10400	11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10500	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10600	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10700	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10800	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10900	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11000	13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11100	13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11200	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11300	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11400	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

110.149.1

Figure A1-1. — Partial range table [illegible]

RANGE	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 12-3. — Partial range table [illegible]

USE OF THE NOMOGRAM

The primary means of determining the change of range for variation of air density is by nomogram (fig. A2-6). The nomogram provided with the 8"/55 caliber range table is an example of the type in use in the Fleet today. When aloft aerological observations are not available, it gives a rapid solution of the error in range due to variation in atmospheric density. Instructions for its use are provided with the nomogram.

The use of the nomogram is more accurate than results obtained from using column 12 with surface observations, as it takes into account the ratio between mean measured and standard density for the actual maximum ordinate obtained.[2] Instructions for using the nomogram are presented later in this appendix.

COLUMNS 15 AND 18

Column 15 is headed "Change in range for 10 knot motion in plane of fire-target" and column 18 is headed "Deflection for—10 knot motion perpendicular to plane of fire-target." Actually, column 15 gives the distance that the target will move in the line of fire, if its speed in the line of fire is 10 knots, during the time of flight of the projectile. Column 18 gives the same information for motion across the line of fire. The values in the columns are derived by multiplying the speed of 10 knots, expressed as 16.89/3 yards per second, by the time of flight of the projectile for the given range, as found in column 4 of the range table.

COLUMNS 13 AND 16

Column 13 is headed "Change in range for 10 knot motion in plane of fire—wind," and column 16 is headed "Deflection for—10 knot motion perpendicular to plane of fire—wind."

A wind, or wind component, in the plane of fire, or line of fire, is spoken of as a range wind. A lateral wind (wind, or wind component, blowing across the line of fire) is spoken of as a cross wind.

The effect of a positive range wind (blowing in the direction in which the projectile is traveling) is to increase the range. The opposite is true for a negative range wind. A cross wind will carry the projectile in the direction toward which the wind is blowing.

The use of the columns is similar to that described earlier for columns 15 and 18.

COLUMNS 14 AND 17

Column 14 is headed "Change in range for 10-knot motion in plane of fire-gun" and column 17 is headed "Deflection for 10-knot motion perpendicular to plane of fire-gun." By "motion of gun" is meant the "velocity imparted to the projectile due to motion of the firing ship," aside from the velocity imparted by the powder charge. This velocity may be positive or negative. Thus, a ship steaming at 10 knots and firing dead ahead imparts an added velocity of 16.89 ft per sec., in the horizontal plane. The same ship firing dead astern reduces the horizontal component of initial velocity by the same amount. Firing on the beam causes a velocity component across the line of fire in the direction of motion of the ship.

If no wind is blowing, a person standing on deck on a moving ship will feel an apparent wind, equal in force to the speed of the ship. It may therefore be said that a projectile fired from a moving ship, in still air, is opposed by an apparent wind equal in force but opposite in direction to the motion of the ship. The effect of such an opposing wind may be found in column 13 for range wind and in column 16 for cross wind.

The relation of columns 13 through 18 may best be understood from the following expressions:

Column 14 = column 15 — column 13, and
Column 17 = column 18 — column 16.

Examination of any range table for any range shows that this relation is true. (The occasional difference of 2 or 3 yards is due to the fact that columns 14 and 17 actually are computed from formulas, the results plotted, and the curves faired.)

DANGER SPACE AND HITTING SPACE

Column 7 of the range table is composed of values of the danger space (chapter 9) for a target 20 feet high and of zero depth in the line of fire.

[2] Some recent range tables, including the one in figure A2-1, have an additional column, 12a, which gives the change in range for a variation of temperature of the air of 10° F. from the standard air temperature. The effect given in column 12a is that caused by change in the elasticity of the air and is independent of and additional to the effect of any change in density. Column 12a is used with surface air temperature, the standard being taken as 59° F.

In the 5"/38 range table, range 10,000 yards, the danger space is 18 yards. The value of the danger space at this range for a target 30 feet high is 30/20 x 18 = 27 yards. Now if this 30-foot target has a beam of 105 feet (35 yards) it is apparent that its danger space is 27 + 35 = 62 yards. Column 13 of the range table, headed "Change in height of impact for variation of 100 yards in sight bar," is the column used for determining hitting space (chapter 5). (Sight bar range is the range shown on the sight scale of the gun at the instant of firing.)

To find the hitting space for a 20-foot target at range 10,000 yards, see column 19. The value obtained is 112 feet; i.e., a variation in sight-bar range of 100 yards will move the point of impact 112 feet in the vertical plane of the target. To raise the point of impact 20 feet (to the top of the target) the sight-bar range would have to be increased $\frac{20}{112}$ x 100 = 18 yards.

This value for hitting space is the same as that earlier obtained for danger space. For most battle ranges this relationship holds; for the shorter ranges, however, there may be a considerable difference.

Column 19 is also used in the computation of the correction for trunnion height and curvature of the earth when figuring the initial ballistic correction. (See the following section.)

DEFINITIONS OF VARIOUS BALLISTIC CORRECTIONS

For shipboard firings, it is necessary to determine, or to estimate, the variations from range-table standard conditions as they exist at the time of firing, and to compute corrections for the errors caused by these variations. The individual corrections are summarized and the result is called a ballistic correction.

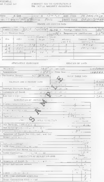
Most of these ballistic corrections are automatically figured by the fire control computer from the initial inputs. However, there are some initial inputs that must be figured separately and set into the computer prior to firing. They are:

1. Arbitrary ballistic correction
2. Correction for first salvo only
3. Initial ballistic correction

The arbitrary ballistic correction, also called arbitrary correction to hit or ACTH, is designed to correct for errors not otherwise accounted for. The correction is developed by exhaustive postfiring analysis of accurate data on ranges, target course and speed, and other elements in past gunnery practices. After all errors which can be accounted for (such as errors in rangefinder ranges and in estimates of target course and speed) have been eliminated in these analyses, there usually remains a certain amount of error in the point of fall for which no cause can be definitely assigned. When enough data have been obtained and analyzed to provide an accurate estimate of this quantity, it is used as an arbitrary ballistic correction.

The correction for first salvo only may be necessary if the initial round fired from a gun has a lower I.V., and therefore a shorter range, than succeeding rounds. This effect was at one time thought to be the result of the lower temperature of the bore; thus, the correction has frequently and erroneously been known as "coldgun correction." It is now known that the loss of velocity is caused by oil in the bore; thus, the correction is needed only if the bore has been cleaned and oiled since the last previous shot was fired. The amount of the correction is derived from experience, as is the ACTH, but it must be considered and treated separately, inasmuch as it is applied for the first salvo only and then removed. The first salvo correction should be used only if experience has shown it to be necessary.

Contemporary gun fire control systems develop automatically many of the inputs required for transmission to the gun mounts. However, there are some factors that must be estimated or figured with pencil and paper and introduced manually into the computer. These collectively constitute the initial ballistic correction. Exactly what goes into the initial ballistic correction depends on the particular fire control systems concerned. In most current types of gun fire systems the initial ballistic correction is inserted as three inputs — initial velocity (I.V.), initial range spot, and initial deflection spot. The next section enumerates the factors that go into the initial ballistic correction and explains how they are figured. Figure A2-2 shows a work sheet (filled in with fictitious values) for the computation of the initial ballistic correction. The work sheet shows which factors go respectively into the I.V. computation, the range correction (i.e., range spot) computation, and the deflection correction (spot) computation.


WORKSHEET FOR THE COMPUTATION OF THE INITIAL BALLISTIC CORRECTIONS

SAMPLE

92.3

Figure A2-2. — Worksheet for the computation of initial ballistic corrections.

COMPUTATION OF INITIAL BALLISTIC CORRECTION

In figure A2-2[3], the values are representative, but are not taken from an actual firing. The lines across the top of the sheet marked "Battery," "Exercise," etc., are for identification purposes.

POWDER AND EROSION DATA

In item "a" in figure A2-2 enter the type powder, index number, and charge weight.

In item "b" enter the nominal velocity. Its value is found in the erosion-data section of the range table. It should be noted that this entry is not always the standard velocity used to compute the range table. In some cases, such as the 5"/38 range table, the expected average velocity of the gun's lifetime is used.

In item "c" enter the average residual temperature of the powder to be fired.

In item "d," "Temperature Coefficient," is obtained from the erosion-data section of the range table OP 551 (3rd revision); in this example the temperature coefficient is 1.2.

Space is provided in item "e" for the erosion data of the individual guns. In this example the eight gun of three 5-inch twin mounts is used. Entries are made for the gun number, the "pseudo equivalent service rounds (PESR)," and bore enlargement or erosion-gage readings. The velocity loss due to erosion is determined by one of these values. When a gun is fired for the first time after star gage or bore erosion gage readings have been taken, the velocity loss is obtained directly from tables in the erosion data section of the range table. When star gage readings are available use the Velocity Loss vs. Bore Enlargement at Origin And Charge Weight Table (table A2-1) for the type powder to be fired.

When bore erosion gage readings are available, use the velocity loss vs. erosion gage reading and charge weight for the type powder to be fired. This table is similar in construction to table A2-1.

Suppose, however, the ship has fired several times since any erosion readings were taken on the gun barrel. In this event, the number of equivalent service rounds fired since the last star gage reading is determined. This number is added to the ESR determined with the star gage reading. This will give the best estimate of the present PESR. This value can then be used to obtain bore enlargement at the origin from table A2-2. With bore enlargement, table A2-1 can be entered to obtain velocity loss due to erosion.

If the powder temperatures vary more than 2° Fahrenheit (F) between guns, the powder temperatures are entered under the heading "Powder Temp. Corr." (fig. A2-2). The velocity loss for each gun is then computed, using the formula in line 1 of the worksheet. If this is done, line 1 of the sheet is left blank. The velocity loss due to powder temperature is combined with the velocity loss due to bore enlargement. This sum is entered in the next column. The 5"/38 gun does not have an erosion corrector in its drive. Therefore, an average powder temperature is used in line 1 of the worksheet, and the average initial velocity loss (7 in this case) is used in line 2 of the worksheet.

ATMOSPHERIC CONDITIONS

Item "f" is the barometer reading in inches, and item "g" is the temperature from the dry bulb thermometer in degrees Fahrenheit. Both are surface readings taken from the ship's instruments located in the ship's bridge. Item "h," "Ballistic Density," is left blank unless this information is available.

TRUNNION AND CURVATURE DATA

We will assume the exercise to be a surface firing with the stable element controlling elevation. Thus, trunnion height and earth curvature corrections are necessary. Item "i" is the average height of the gun trunnions above the waterline. Item "j" is the earth's curvature for the range listed in table A2-3. Item "k" is the sum of items "i" and "j."

ROTATION OF THE EARTH

This correction is omitted for guns of 5-inch and below.

[3]The forms reproduced in figures A2-2 through A2-5 are marked CONFIDENTIAL when filled in with data pertaining to an actual gunnery practice, and must be so treated. In this case, however, the data used are purely hypothetical.

Table A8-5. — Velocity loss vs bore enlargement at origin and chest weight.

SPCG SPCN SPD and SPCW BODIES

[illegible]	[illegible]

Approved: [illegible]

Reviewed: [illegible]

U. S. Naval Proving Ground, Dahlgren, Virginia

Table A2-2. — 5"/38 caliber guns Mk 12 Mod 1

BORE ENLARGEMENT AT ORIGIN vs EQUIVALENT SERVICE ROUNDS

ESR	0	10	20	30	40	50	60	70	80	90
0	.000	.001	.002	.002	.003	.003	.004	.005	.006	.007
100	.008	.009	.011	.012	.013	.015	.016	.018	.020	.021
200	.024	.027	.029	.031	.033	.037	.040	.042	.044	.045
300	.048	.050	.051	.054	.055	.057	.059	.060	.061	.062
400	.065	.067	.068	.069	.071	.074	.075	.075	.076	.077
500	.078	.079	.081	.082	.083	.084	.085	.086	.087	.088
600	.089	.090	.092	.092	.093	.094	.095	.096	.096	.097
700	.098	.099	.100	.101	.102	.102	.103	.104	.105	.105
800	.106	.107	.108	.108	.109	.110	.110	.111	.112	.112
900	.113	.114	.114	.115	.116	.116	.117	.117	.118	.119
1000	.119	.120	.121	.121	.122	.123	.123	.123	.124	.124
1100	.125	.125	.126	.127	.127	.128	.128	.129	.129	.130
1200	.130	.130	.131	.132	.132	.133	.133	.133	.134	.134
1300	.135	.135	.136	.136	.137	.137	.138	.138	.138	.138
1400	.139	.140	.140	.140	.141	.141	.142	.142	.143	.143
1500	.143	.144	.144	.144	.145	.145	.146	.146	.146	.147
1600	.147	.147	.148	.148	.149	.149	.149	.150	.150	.150
1700	.151	.151	.151	.152	.152	.152	.153	.153	.153	.154
1800	.154	.154	.155	.155	.155	.156	.156	.156	.157	.157
1900	.157	.158	.158	.158	.159	.159	.159	.159	.160	.160
2000	.160	.161	.161	.161	.162	.162	.162	.162	.163	.163
2100	.163	.163	.164	.164	.164	.164	.165	.165	.165	.165
2200	.166	.166	.166	.167	.167	.167	.168	.168	.168	.168
2300	.169	.169	.169	.169	.170	.170	.170	.170	.171	.171
2400	.171	.171	.172	.172	.172	.172	.173	.173	.173	.173
2500	.174	.174	.174	.174	.174	.175	.175	.175	.175	.176
2600	.176	.176	.176	.177	.177	.177	.177	.177	.178	.178
2700	.178	.178	.179	.179	.179	.179	.179	.180	.180	.180
2800	.180	.180	.181	.181	.181	.181	.182	.182	.182	.182
2900	.182	.183	.183	.183	.183	.183	.184	.184	.184	.184
3000	.184	.185	.185	.185	.185	.185	.186	.186	.186	.186
3100	.186	.186	.187	.187	.187	.187	.187	.188	.188	.188
3200	.188	.188	.188	.189	.189	.189	.189	.189	.190	.190
3300	.190	.190	.190	.191	.191	.191	.191	.191	.191	.192
3400	.192	.192	.192	.192	.192	.193	.193	.193	.193	.193
3500	.193	.194	.194	.194	.194	.194	.194	.195	.195	.195
3600	.195	.195	.195	.195	.196	.196	.196	.196	.196	.197
3700	.197	.197	.197	.197	.197	.198	.198	.198	.198	.198
3800	.198	.198	.199	.199	.199	.199	.199	.199	.200	.200
3900	.200	.200	.200	.200	.200	.201	.201	.201	.201	.201
4000	.201	.202	.202	.202	.202	.202	.202	.202	.203	.203
4100	.203	.203	.203	.203	.203	.204	.204	.204	.204	.204
4200	.204	.204	.205	.205	.205	.205	.205	.205	.205	.205
4300	.206	.206	.206	.206	.206	.206	.206	.207	.207	.207
4400	.207	.207	.207	.207	.208	.208	.208	.208	.208	.208
4500	.208	.208	.209	.209	.209	.209	.209	.209	.209	.210
4600	.210	.210	.210	.210	.210	.210	.210	.211	.211	.211
4700	.211	.211	.211	.211	.211	.211	.212	.212	.212	.212
4800	.212	.212	.212	.212	.212	.213	.213	.213	.213	.213
4900	.213	.213	.214	.214	.214	.214	.214	.214	.214	.214
5000	.215	.215	.215	.215	.215	.215	.215	.215	.216	.216
5100	.216	.216	.216	.216	.216	.216	.216	.217	.217	.217
5200	.217	.217	.217	.217	.217	.217	.218	.218	.218	.218
5300	.218	.218	.218	.218	.218	.219	.219	.219	.219	.219
5400	.219	.219	.219	.219	.219	.219	.220	.220	.220	.220
5500	.220	.220	.220	.221	.221	.221	.221	.221	.221	.221
5600	.221	.221	.221	.222	.222	.222	.222	.222	.222	.222
5700	.222	.222	.223	.223	.223	.223	.223	.223	.223	.223
5800	.223	.223	.224	.224	.224	.224	.224	.224	.224	.224
5900	.224	.224	.225	.225	.225	.225	.225	.225	.225	.225

Bore Enlargement at Origin in Inches

110,124

Table A2-3. —Curvature of earth, feet

R yds	0	100	200	300	400	500	600	700	800	900
1,000	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8
2,000	.9	.9	1.0	1.1	1.2	1.3	1.5	1.6	1.7	1.8
3,000	1.9	2.1	2.2	2.3	2.5	2.6	2.8	2.9	3.1	3.3
4,000	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2
5,000	5.4	5.6	5.8	6.1	6.3	6.5	6.8	7.0	7.2	7.5
6,000	7.8	8.0	8.3	8.5	8.8	9.1	9.4	9.7	10.0	10.3
7,000	10.6	10.9	11.2	11.5	11.8	12.1	12.4	12.8	13.1	13.4
8,000	13.8	14.1	14.5	14.8	15.2	15.6	15.9	16.3	16.7	17.1
9,000	17.4	17.8	18.2	18.6	19.0	19.4	19.8	20.3	20.7	21.1
10,000	21.5	22	22	23	23	24	24	25	25	26
11,000	26	27	27	28	28	28	29	29	30	31
12,000	31	32	32	33	33	34	34	35	35	36
13,000	36	37	38	38	39	39	40	41	41	42
14,000	42	43	44	44	45	46	46	47	47	48
15,000	48	49	50	51	51	52	53	53	54	55
16,000	55	56	57	58	58	59	60	61	61	62
17,000	62	63	64	65	66	66	67	68	69	69
18,000	70	71	72	73	73	74	75	75	76	77
19,000	78	79	80	81	81	82	83	84	85	85
20,000	86	87	88	89	90	91	92	93	94	94
21,000	95	96	97	98	99	100	101	102	103	104
22,000	104	105	106	107	108	109	110	111	112	113
23,000	114	115	116	117	118	119	120	121	122	123
24,000	124	125	126	127	128	129	131	132	133	134
25,000	135	136	137	138	139	141	142	143	144	145
26,000	146	147	148	149	150	152	153	154	155	156
27,000	157	159	160	161	162	163	164	165	167	168
28,000	169	171	172	173	174	175	177	178	179	180
29,000	181	183	184	185	186	188	189	190	192	193
30,000	194	195	197	198	199	201	202	203	205	206
31,000	207	209	210	211	213	214	215	217	218	219
32,000	221	222	224	225	226	228	229	231	232	233
33,000	234	236	238	239	240	242	243	245	246	247
34,000	249	251	252	253	255	257	258	259	261	262
35,000	264	265	267	268	270	272	273	275	276	277
36,000	279	281	282	284	286	287	289	290	292	293
37,000	295	297	298	300	302	303	305	307	308	309
38,000	311	313	315	317	318	319	321	323	325	326
39,000	328	329	331	333	335	336	338	340	342	343
40,000	345									
R yds	0	100	200	300	400	500	600	700	800	900

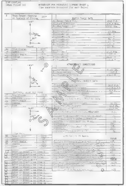
110,125

RANGE TABLE DATA

The best estimate of firing range is entered as item A in figure A2-3. Using this range, take items B, C, D, and E from the range table (fig. A2-1).

COMPUTATION OF INITIAL VELOCITY

Velocity loss should first be computed. Line 1 is the error in I.V. due to a variation in powder temperature from 90° F. It should be noted that



93.4
Figure A2-3. — Worksheet for preparing Gunnery Sheet 4.

if the temperature is greater than 90°F, the sign is negative (−), even though an increase in range results. The reason for this is not obvious, but a study of line 1 in comparison with lines 2 and 3 will clarify it. Line 2 is always a velocity loss (since erosion never increases I.V.). The effect of a powder temperature above 90°F. will reduce this loss, while a powder temperature below 90° F will increase the loss. Line 3, which is the algebraic sum of lines 1 and 2, will therefore be of the correct sign if powder temperature correction is treated as described above. Should line 3 result in a minus sign, it would indicate a velocity gain. Such a case could occur with a new gun when firing powder from a magazine where the powder temperature was above 90°F. This will rarely happen.

Line 4 is the nominal velocity from item "b." Line 5 is the expected I.V. which is found by subtracting the Total Velocity Loss (line 3) from the Nominal Velocity (line 4). This result (line 5) is the expected initial velocity of the projectile, and should be set into the computer.

COMPUTATION OF RANGE CORRECTION

To begin with, the difference between the expected impact point for standard conditions and the expected impact point for existing conditions is dealt with. The entry in line 5 has been determined from the nomogram (appendix B, part 2) in the range table. When ballistic density (item "h") is used, the formula in line 6 will give the proper value of range correction due to density. If item "h" is greater than 100%, the entry is made in the "Short" column; if less than 100%, the entry is made in the "Over" column. Line 7 is the range change due to variations of the air temperature from standard. If the air temperature is above standard, the entry is made in the Short column; if below standard, the entry is made in the Over column.

The trunnion height and curvature entry in line 8 is always "over." Column 19 of the range table gives the change in height of impact due to a 100-yard change in range. These values assume the gun and target are in the horizontal plane. Trunnion height and earth's curvature are the amounts the problem deviates from the horizontal plane. Since the problem is concerned with total deviation from the horizontal, these factors can be combined. The formula in line 8 results in the number of yards by which range must be changed to compensate for total deviation.

No compensation is made for earth's rotation in the 5"/38 battery. Therefore, line 9 is left blank. Line 10, "Other Range Errors," is provided for range errors which are normally not encountered. Under this heading in the example is projectile weight. The range table is based on a projectile weight of 55.18 pounds, however the projectile in this example weighs 56 pounds. The formula used to calculate the compensation for the effect of a variation in projectile weight is shown in the table below.

range table weight	actual weight	weight difference	x column 11 =		
55.18	56	+.82	x	26	=21.3

Column 11 of the range table gives the effect on range due to a decrease in weight. Since in the example the projectile is heavier, range is increased. Therefore, 26 rather than −26 is used to compute range change. Projectiles heavier than standard will leave the gun at a lower initial velocity, which results in a decrease in range. The heavier projectiles, however, have an increase in ballistic coefficient which results in an increase in range. At short ranges the change in initial velocity has the greater effect, but at long ranges the ballistic coefficient has the greater effect.

Line 11 is the algebraic sum of the range errors. Note that the column headings have been changed from "Over" to "Drop" and from "Short" to "Add." In this manner the errors are converted to corrections. These are reciprocal quantities.

The Arbitrary Correction To Hit (ACTH) in line 12 and the correction for first salvo only in line 13 are obtained from experience within the individual battery. The ACTH remains throughout the firing, but the value of line 13 is removed after the first salvo.

Line 14 is the algebraic sum of the range corrections. This value is set into the computer as a range spot. In AA fire the range correction is sometimes converted to an initial velocity correction. When this is done the first salvo correction is not included, and the trunnion height and earth curvature corrections are not needed. The formula to convert range correction to initial velocity correction is:

$$\frac{\text{Range correction} \times 10}{\text{Column 10}} = \text{Initial velocity correction}$$

COMPUTATION OF DEFLECTION CORRECTION

Line 15 indicates the error in deflection due to earth's rotation. As in the computation for range deflection, it is used only in batteries larger than 5-inch. The error's value and sign are obtained from the range table.

Line 16, "Other Deflection Errors," is provided for deflection errors which are normally not encountered.

The formula in line 17 is used to convert yards to mils. Deflection is normally spotted in mils. Note that the column headings have been changed from "Right" to "Left" and from "Left" to "Right." As in range, we are converting from the error to the correction. The ACTH in line 18 is obtained from previous gunnery exercise. Line 19 is the total deflection correction and is applied to the computer as a deflection spot.

POSTFIRING ANALYSIS: GUNNERY SHEET 4

It has been said, "The best rangefinder is the gun." This implies that the effectiveness of a fire control system is shown by the actual impact point of the projectile. Postfiring analysis concerns itself with a comparison between the observed impact point and the correct theoretical position of the impact point. From this comparison, consistent errors which cannot be accounted for are determined. ACTH in range and deflection is computed from these errors. The most satisfactory results are obtained when error-producing factors (such as relative motion and initial ballistic calculation) are held to a minimum. The ACTH is normally computed from a particular gunnery exercise. This exercise, normally a Z-24-G, should be held under as nearly ideal conditions as possible. The battery should have been accurately aligned, and the fire control system should have been brought to peak performance.

Standard procedure and standard forms are used to determine the ACTH. The standard form is Gunnery Sheet 4, shown in figures A2-4 and A2-5. A worksheet (fig. A2-3) is used in conjunction with the finished smooth Sheet 4. (The worksheet is prepared locally and may vary from the example shown.) Observers record the needed information available aboard ship for each salvo. The location of the impact point or mean point of impact (MPI) is obtained from a spotting or photographic party. Spotting procedures were covered in chapter 9.

Figures A2-4 and A2-5 show a sample problem of a salvo from the right guns of the twin 5" mounts of a destroyer battery. The values in the figures are representative but are not from an actual exercise.

POSTFIRING ANALYSIS: PREPARATION OF WORKSHEET

A separate worksheet should be used for each salvo. The worksheet represents a complete picture of the conditions that existed at the instant the salvo was fired.

Range Table Data

In item A (fig. A2-3) enter the initial velocity for which the range table (fig. A2-1) is computed. The 5" range table (OP 551 3rd revision) is computed for 2600 foot-seconds.

In item B enter the gun's angle of elevation above the horizontal plane at the time of firing. When the stable element controls elevation, this value is obtained from sight angle. Since 2000 minutes represents zero sight angle, we have subtracted 2000 from the value of sight angle in the computer.

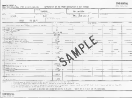
When the director controls elevation, sight angle is the angle between the LOS and the LOF. In this case trunnion height and earth curvature corrections are converted to minutes of arc and subtracted from sight angle. This brings the LOS into the horizontal plane. In batteries which have individual erosion correctors, the settings on the corrector affect gun elevation. The velocity loss in foot-seconds is converted to minutes of arc and subtracted from sight angle.

Item C is the range table value corresponding to item B. In the example, a range of 16,100 corresponds to an angle of elevation of 575.6 minutes above the horizontal plane.

Items D through N are taken directly from the range table, using the range in item C. The remainder of the worksheet is used to compute the initial velocity, range, and deflection problems of the exercise.

POSTFIRING ANALYSIS: COMPUTATION OF ARBITRARY CORRECTION TO HIT (RANGE)

The first lines on Gunnery Sheet 4 (fig. A2-8) are for identification purposes and in general



23.4
Figure 23-6.—Gunnery Sheet 6—

[illegible]

CONFIDENTIAL

SAMPLE

[illegible]	[illegible]							
1 [illegible]	+8							
2 [illegible]	[illegible]							
3 [illegible]	[illegible]							
4 [illegible]	[illegible]							
5 [illegible]	—							
6 [illegible]	[illegible]							
7 [illegible]	[illegible]							
8 [illegible]	[illegible]							
9 [illegible]	-2							
10 [illegible]	[illegible]							
11 [illegible]	0							

[illegible]

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65.4

Figure AB-8.—Summary Sheet 6 — [illegible] Deflection.

are self-explanatory. However, the space labeled "RUN" is normally used to identify the projectile/fuze combination and the weight of the combination.

Item "a," "Number of Guns," refers to the number of guns actually fired. If, for example, a 6-gun salvo was intended, but due to a casualty only five guns fired, the proper entry is 5.

In item "b," "Number of Cold Guns," enter the number of guns firing their initial round since the barrel was last cleaned and oiled. It should be assumed that the guns were fired just previous to this exercise. Therefore the entry is zero.

Item "c," "Guns Fired," identifies guns by barrel or mount number and position in the barrel or mount. The right guns of mounts 1, 2, and 3 were fired in this hypothetical practice.

Items "d," "e," "f," "g," "h," and "j" are obtained from the worksheet. It is essential that the sign be carried with transferred values. Item "i" is zero in the example. (This correction is always omitted for guns of 5-inch and smaller caliber.)

The total for items "k," "l," and "m" is combined in the computations on the worksheet. Although the computed I.V. of 2561 foot-seconds would cause a decrease in range from the values taken from a 2600 foot-second range table, it does cause an increase in the range values taken from the 2500 foot-second range table which is being used in computing values in the example. Therefore, the sign is PLUS for this entry of 381 yards.

Item "o," the expected range, is the gun range corrected for all known variations from standard range table conditions which affect the projectile in flight, plus trunnion height and earth's curvature. It should be noted that the target motion does not enter into this computation, because the value of expected range applies to the point of fall of the projectiles and is to be used for comparison with the actual range to the point of fall.

Item "p" is the navigational range at the instant of firing. The most accurate and carefully calibrated radar should be used to obtain this figure.

Item "q" is obtained from the worksheet, using care in selecting the proper sign. Since in the example the target is closing, the range will decrease during the time of flight of the projectile.

Item "r," the error of MPI, represents the actual difference between the position of the target at the instant of the fall of the projectiles and the mean point of impact of the several shots. MPI was discussed in greater detail in chapter 9.

For this use in postfiring analysis, the best available data on the points of fall of individual projectiles should be used. When a camera party is available, the best data is obtained by triangulation of aerial photographs. OVERs carry the plus (+) sign; SHORTs carry the minus (-). An arbitrary value of +140 for error of MPI is used in figure A2-4.

Item "s" represents the actual range to the point of fall of the projectiles fired. Item "t," therefore, represents the otherwise unaccounted-for errors, the average value of which is used as ACTH in range.

POSTFIRING ANALYSIS: COMPUTATION OF ARBITRARY CORRECTION TO HIT (DEFLECTION)

Item "u" (fig. A2-5) is the difference between the midpoint of the deflection scale and the actual scale reading. It is the number of mils between the plane through the LOS and the plane through the LOF at the instant the gun was fired. The sign is + if the scale reading is to the right of the midpoint and - if to the left. In the example the scale reading was 503.

Items "v," "w," and "x"—47.7, 160, and 40 yards, respectively in this example—are taken from the worksheet. The proper sign is important.

Item "y" is similar to item "i" and its value is zero in this example for the reason previously stated.

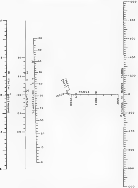
Item "z," it will be noted, includes a conversion from yards to mils at the actual range.

Item "aa," the expected deflection, consists of the deflection used, corrected for drift and those variations from standard range table conditions which affect the projectile while it is in the air. This item serves the same purpose in deflection as item "o" in range.

Item "bb" is obtained from the worksheet.

Item "cc" is the error of the MPI in mils, obtained by photo triangulation or observation. If the MPI is right of the target, the sign is +, if left -. In the example, the error of the MPI was 2 mils left.

Item "dd" is the actual deflection of the MPI in mils. It is the perpendicular distance (converted to mils) from the vertical plane through the line of sight to the mean point of impact.



110.189
Figure A2-6. — Change in range for variation in density of air.

This item is the deflection equivalent of item "z" above.

Item "ee," the ACTH in deflection, is obtained by subtracting item "aa" from item "dd." Like item "t" in range, it represents the errors otherwise unaccounted for. The ACTH in range and deflection represent the two values which are found through the processes of postfiring analysis.

AIR-DENSITY NOMOGRAM: INSTRUCTIONS FOR USING

To understand how the nomogram is used, refer to figure A2-6 and use the information given in the following example:

Barometric pressure. . . . . 29.1 inches
Temperature . . . . 80° F.
Range. . . . . 8,000 yards

Using a straightedge, connect points 1 and 3 of scales B and T to obtain density (point 2 on scale D).

Similarly, connect points 2 and 4 of scales D and R to obtain change in range (point 5). Change in range is +210 yards in this example.

NOTE. — The best estimate of ballistic density to different altitudes is in very close, but not in exact agreement with standard density when surface conditions are standard. When surface density is not standard the disagreement is usually greater and is a function of surface density and maximum ordinate. Use of this nomogram will not give agreement with results obtained from column 12 of the range table and surface observations only, but it should be a more accurate figure because it takes into account the ratio between mean measured and standard density for the actual maximum ordinate obtained.

APPENDIX III

ORDNANCE SAFETY PRECAUTIONS

The purpose of this appendix is to impress upon you the need and reason for rigid adherence to safety precautions, and to point out the grave consequences that may result from violation of these precautions.

Printed precautions alone cannot prevent accidents. Safe operating procedures must be explained in detail by those who know to those who do not know. Safety is not a one-day-out-of-the-week event, but a daily affair that must be instilled by constant supervision, careful instruction, and adequate training. Safety is both the result and the reflection of good training. The two are inseparable. A well trained crew is necessarily a safety-minded crew.

Safety education is economical. It has been shown beyond any doubt that proper safety training saves untold dollars and lives. The amount of time and money spent for teaching safety totals far less than the hours and dollars lost in a single major accident. Safety can be taught in many ways. Initial training requires instruction in the basic maintenance, operation, and potential danger of any weapon or explosive. Drills must include exercises in safety as well as in mechanical operation. Safety precautions should be explained, and the reason for their existence and the terrible consequences of not following them must be emphasized frequently. Discussions, lessons, practice, and explanations of safety practices must be repeated until every crew member is safety conscious.

The first section of this appendix lists safety precautions especially pertinent to the junior officer. Because officers are particularly responsible for the military safety program, you can expect to be in a position where you will have specific responsibilities for safety.

Another section gives actual case histories that clearly illustrate the safety problem. The cases included are but a few of many that could have been prevented. Although some of these cases are quite old, their value as safety reminders has not diminished. This section is abridged from OP 1014 (2nd revision), entitled Ordnance Safety Precautions, Their Origin and Necessity. This revision (or a later revision) of the OP should be available at your first duty station. It will be well worth your while to read it, as well as OP 3347, United States Navy Ordnance Safety Precautions.

LIST OF SAFETY PRECAUTIONS

The list of safety precautions in this section is quoted from the appendix of OP 1014 and from OP 3347. It is emphasized that the following is NOT a complete listing of all ordnance safety precautions. A complete listing may be found in OP 1014 and OP 3347. It is important to remember that observance of all safety precautions is imperative. In circumstances which conflict with their requirements, or if for other reasons changes in or additions to them are required, the responsible Navy authority must be informed. If there is any doubt as to the exact meaning of a safety precaution, an interpretation should be requested from NavOrd. Conditions not covered by the safety precautions may arise that, in the opinion of the commanding officer, may render further operation of the equipment unsafe. Under these conditions, nothing in the safety precautions should be construed as authorizing such further operation.

The following list of safety precautions frequently refers to the "Bureau of Naval Weapons." Whenever you see this reference, remember that this refers to what is now the Naval Ordnance Systems Command and the Naval Air Systems Command.

1. SAFETY DEVICES.—Safety devices provided shall always be used as designated to prevent possibility of accident, and shall be kept in good order and operative at all times.

All instructions promulgated by competent authority to insure safe operation or handling of equipment shall be strictly observed.

2. SAFETY WATCH FOR MOVING UNITS. — Whenever any motion of a power-driven unit is capable of inflicting injury on personnel or material not continuously visible to the person controlling such motion, the officer or petty officer who authorizes the unit to be moved by power shall, except at general quarters, insure that a safety watch is maintained in areas where such injury is possible both outside and inside the unit, and shall have telephone or other effective voice communication established and maintained between the station controlling the unit and the safety watch. These precautions are applicable to turrets, gun mounts, guns, directors, rangefinders, searchlights, torpedo tubes, rocket launchers, and similar units. Under the conditions stated above, the station controlling shall obtain a report "all clear" from each safety watch before starting the unit. Each safety watch shall keep his assigned area clear and if unable to do so shall immediately report his unit fouled, and the controlling station shall promptly stop the unit until it is again reported clear.

3. WARNING SIGNALS. — In turrets and unclosed mounts, a warning signal shall be installed outside the turret or mount; and whenever power train is used, except at general quarters, the officer or petty officer in charge of the turret or mount shall cause warning signals to be sounded before using power and at intervals during its use.

4. CHANGES IN MATERIALS. — Changes, modifications in, or additions to ordnance material, or other material used in connection therewith, shall not be made without explicit authority from the bureaus (naval systems commands) concerned.

5. DESIGNATED USE OF EXPLOSIVES. — No ammunition or explosive assembly shall be used in any gun or appliance for which it is not designated.

6. DRILL AMMUNITION. — No other than drill ammunition shall be used for drill.

7. AA FIRING. — Except in action or when specifically authorized, antiaircraft guns shall not be fired at elevations greater than, or fuze settings less than, those prescribed in the current orders for Gunnery Exercises. When firing antiaircraft guns as such, all personnel not required to be exposed shall be kept under cover.

8. SUPERVISION. — As familiarity with any work, no matter how dangerous, is apt to lead to carelessness, all persons who may supervise or perform work in connection with the inspection, care, preparation, use, or handling of ammunition, or explosives —

(a) Shall exercise the utmost care that all regulations and instructions are rigidly observed.

(b) Shall carefully supervise those under them and frequently warn them of the necessity of using the utmost precaution in the performance of their work.

No relaxation of vigilance shall ever be permitted.

9. AMMUNITION TRANSFER. — Except in case of emergency, ammunition shall not be transferred during fueling operations.

10. HIGH TEMPERATURE. — All ammunition, explosives, and powder shall be protected from abnormally high temperature. If so exposed, they shall be handled in accordance with current instructions of the Bureau of Naval Weapons. Permissible maximum storage temperatures shall be prescribed by the Bureau of Naval Weapons.

11. SMOKELESS POWDER. — Smokeless powder which shows unmistakable signs of advanced decomposition shall be disposed of in accordance with current instructions of the Bureau of Naval Weapons.

12. HANDLING. — To minimize the risk of fire, explosion, and damage to ammunition and its containers from accidental causes, ammunition shall be handled as little as practicable. As the action of denting thin-cased high-explosive ammunition is known to have caused detonation of the explosive in some instances, special care shall be exercised to insure that such ammunition is never struck, dropped, or bumped.

13. DEFECTIVE AMMUNITION. — Defective bomb type and thin-case ammunition shall be disposed of in accordance with current instructions of the Bureau of Naval Weapons.

14. DROPPING FUZED PROJECTILE. — A fuzed projectile, whether in a container or not, if dropped from a height exceeding 5 feet shall be dumped overboard in a manner conforming with regulations for dumping ammunition at sea except when practicable to turn the projectile in to a Naval Ammunition Depot. Such ammunition shall be handled with the greatest care.

15. STRIKING FUZED PROJECTILE. — Care must be used to avoid tapping or otherwise striking fuzed projectiles. This precaution is particularly applicable to attempts to loosen

such a projectile in the cartridge case by repeated light blows of a mallet, unloading such a projectile wedged in the bore of a gun, and the striking of a projectile by the recoil of a gun or an ejected case.

16. SWITCHES. — The covers of switches, circuit breakers, etc., shall be kept securely closed while powder is exposed in the vicinity.

17. MAGAZINES. — Magazines shall be kept scrupulously clean and dry at all times. Nothing shall be stored in magazines except explosives, containers, and authorized magazine equipment. Particular attention shall be paid that no oily rags, waste, or other foreign combustibles are stored in them.

18. NAKED LIGHTS. — Naked lights, matches, or other flame-producing apparatus shall never be taken into magazines or other spaces used primarily as magazines while these compartments contain explosives.

19. EXCESSIVE HEAT. — Before performing any work which may cause either an abnormally high temperature or an intense local heat in a magazine or other compartment used primarily as a magazine, all explosives shall be removed to safe storage until normal conditions have been restored.

20. BLACK POWDER. — Black powder is one of the most dangerous of explosives and shall always be kept by itself. Only such quantities as will meet immediate needs shall be taken from the magazines. A container of black powder shall never be opened in a magazine nor in the vicinity of a container in which there is any explosive.

21. ALTERING AMMUNITION. — Ammunition shall not be altered, nor shall fuzes or any other parts be removed or disassembled without explicit instructions from the Bureau of Naval Weapons.

22. TRIAL LOADING. — Live ammunition shall be loaded into guns for firing purposes only. Test or inspection of ammunition by fitting it into guns is prohibited, except when authorized by specific instructions of the Bureau of Naval Weapons.

23. EXCESS AMMUNITION. — During firing no other ammunition than that immediately required shall be permitted to remain outside of the magazine.

24. ASSEMBLING CHARGES. — During gunnery exercises, charges in excess of the amount required to be available for one run shall not be assembled in the vicinity of guns mounted outside of turrets. No charge for a bag gun shall be removed from its tank, nor shall the tops of tanks be removed or so loosened that the bags may be exposed to flame until immediately before the charge is required for loading.

25. FLAME-PROOF COMPARTMENTS. — When either cartridges or bag charges are outside the magazines, each flame-proof compartment or space which forms a stage of the ammunition train, including the magazine and gun compartments (in or out of turrets), shall, wherever practicable, be kept closed from all other compartments or spaces except when the actual passage of ammunition requires it to be open. Where practicable, no flame-proof stage of the ammunition train shall be open to both the preceding and the following stages at the same time.

26. POSITION OF BREECH. — The limiting position of the breech of the gun on recoil shall be indicated and the gun crew shall be instructed to keep clear.

27. UNLOADING GUN. — While a gun is being unloaded, all personnel not required for the unloading operation shall be kept at a safe distance from the gun.

28. RAMMING DEVICES. — Only approved ramming devices and methods shall be used in loading live cartridges. Any cartridge which does not freely and fully enter the chamber of the gun shall be carefully extracted and put aside, and no further attempt shall be made to fire such a cartridge.

29. OPENING OF BREECH. — Effective measures shall be taken to guard against prematurely opening the breech of a loaded gun, whether or not the gun is fitted with a salvo latch.

30. LOADED GUN. — If a gun is loaded at the order "cease-firing" —

(a) The gun shall be kept pointed and trained in a safe direction.

(b) The breech mechanism shall be kept fully closed.

(c) The gun shall normally be cleared by firing as soon as practicable.

31. FUZED PROJECTILE IN HOT GUN. — A loaded and fuzed projectile, seated in the bore of a gun that is hot from previous firing, presents a hazard, since detonation of the projectile is possible as a result of being heated. Whenever practicable, such projectile should be disposed of promptly by firing the round. Whether a gun is hot or cold, the risks attendant upon removing a loaded and fuzed projectile seated in the bore by backing out are considered unwarranted except in the case of guns for which existing instructions specifically prescribe this procedure.

32. OBSTRUCTED LINE OF FIRE.—Ships shall cease the firing of any gun whose line of fire is endangering any objects other than the designated target. These objects include friendly ships and aircraft and own ship's structure together with the mounts and launchers and their barrels, fixed or moving. This stipulation applies to objects in the vicinity of the firing point, throughout the trajectory and in the vicinity of the target. Turrets, mounts, guns, and launchers which are not firing, while others are firing, shall be trained and elevated if manned, or secured if unmanned, in a manner that will provide the greatest amount of safety from the firing. This position of greatest amount of safety of the unmanned mounts will generally be that position which the firing cut-out mechanism cams of the firing mounts were cut to clear.

33. ARMED AMMUNITION.—Since it is not always possible to ascertain readily whether mines, depth charges, rockets, projector charges, and aircraft bombs have been inadvertently armed in storage or handling, all of these types, when fuzed or assembled with firing mechanisms, shall at all times be handled and treated as if armed, in strict conformity with the instructions for safeguarding against the inadvertent arming, firing, or launching of such ammunition.

34. REMOVING FUZES.—Fuzes, firing mechanisms, or primer mechanisms for bombs, depth charges, rockets, projector charges, demolition outfits, or mines shall not, except as covered by special orders or current instructions of the Bureau of Naval Weapons, be removed, disassembled, repaired, or in any way altered.

35. STORING FUZED ORDNANCE.—Bombs, rocket heads, and projector charges, for which fuzes are issued separately, shall not be stowed with those fuzes installed in or near magazines containing explosives.

36. STORING FUZES.—Fuzes issued separately for bombs, rockets, and projector charges, which contain integral detonators or other explosive components, shall be stored only in specially designated fuze magazines which shall not be located adjacent to magazines containing high explosives.

37. STORING DETONATORS.—Detonators which are not assembled integrally with fuzes shall be stored only in standard type detonator lockers located in approved places.

38. REMOVING FUZE ARMING.—Fuze-arming wires or devices shall not be removed from the unarmed position until just before releasing or firing. Safety pins or other devices requiring removal before flight, or firing, shall not be removed until the ammunition has been loaded in racks, projectors, or launchers and not until after the arming wire or device has been put in place. Bombs, mines, depth charges, rockets, or projector charges not expended shall be made "safe" at the first opportunity in accordance with current instructions for the respective assemblies. When handling or unarming an accidentally armed fuze, the prescribed procedure shall be carefully followed.

39. ELECTRONIC COMPONENTS.—Electric igniters, primers, or detonators, electrically fired rocket and guided missile motors, electric or electronic ordnance fuzes, including VT fuzes, shall not be stowed in the same compartment with, to be exposed within five feet of, any exposed electronic transmitting apparatus or exposed antenna or antenna lead, except where such electronic apparatus or antenna is a part of authorized test equipment of a weapon or is integral with a weapon containing such components, in which event special instructions pertinent thereto shall apply.

40. RECOVERING TORPEDO.—In recovering a torpedo in the water the propeller lock shall be put on at the first opportunity and kept on until the torpedo is safely landed.

41. TORPEDO TORCH POTS.—Because the filling material used in torpedo torch pots ignites spontaneously or forms poisonous gas when combined with water, or subjected to moisture, extreme care must be taken to follow existing Bureau of Naval Weapons instructions concerning the handling of torch pots.

42. ELECTRIC TORPEDOES.—The use of electric torpedoes involves hazards of mechanical injuries, electrical shock or burn, acid burns, and hydrogen explosion or combustion. Bureau of Naval Weapons instructions prescribe effective measures to prevent accidents and shall be rigidly adhered to at all times.

43. PYROTECHNIC MATERIAL.—Pyrotechnic material shall always be kept by itself in regular pyrotechnic storage spaces, if such are provided, or in pyrotechnic lockers on upper decks. In using it, only a minimum amount shall be exposed.

44. PATH OF EXHAUST.—All personnel shall keep clear of the possible exhaust path of rockets at all times.

45. ROCKET MISFIRES.—In case of rocket misfire, personnel shall not approach the rocket for at least 10 minutes, nor until firing circuits

are known to be open. This, at the discretion of the commanding officer, is not obligatory in time of action.

46. BLOWBACK. – In firing small arms, machine guns, and submarine guns, whenever a blow-back occurs, the bore shall be examined for foul bore before firing another round.

47. SMALL ARMS. – Safety precautions in Army Regulations AR-385-63, Safety Regulations for firing ammunition, training, target, and combat shall apply to all small arms firing by Navy or Marine Corps personnel.

48. HAZARDOUS PROCEDURES. – Officers or supervisors must be alert to detect any hazardous procedures or practices and symptoms of a deteriorating mental attitude, and take timely corrective action.

49. INOPERATIVE SAFETY DEVICES. – Safety devices must not be bypassed nor made inoperative except in accordance with approved instructions. If they are inoperable for any reason, warning signs should be used to inform everyone of the increased hazard.

50. SMOKING. – Smoking is not permitted in magazines, nor in the immediate vicinity of handling or loading operations involving explosives or ammunition.

51. PERSONNEL INSTRUCTION. – All personnel required to handle ammunition shall be carefully and frequently instructed in the safety precautions, methods of handling, storage and the uses of all kinds of ammunition and explosive ordnance with which the vessel, aircraft unit, or station may be supplied. No one shall be permitted to inspect, prepare, or adjust live ammunition and explosives until he thoroughly understands his duties, the precautions and the hazards involved.

Personnel assigned to operate any ordnance equipment shall receive, prior to commencing operation, a thorough indoctrination in general safety precautions applicable to ordnance and in the specific precautions applicable to the equipment they operate. Periodic drills shall be conducted to provide realistic training for operation of ordnance equipment, and to note and eliminate any unsafe practices. New or inexperienced personnel must not be permitted to work independently on explosive ordnance of any kind, but shall be under the direct and continued supervision of skilled and experienced personnel, until adequate experience is acquired.

CASES OF ORDNANCE CASUALTIES

As stated earlier, some of the cases of ordnance casualties are quite old. More recent examples (in most cases) cannot be used because of security classification.

1. Aboard a destroyer in May 1949, a gunner's mate was cleaning and chipping paint off a 40-millimeter gun mount. For some reason, and in violation of existing orders, he removed the cover plate from the train motor control switch box. Perhaps he meant to clean it. Minutes later he was found on the deck, dead. He had been electrocuted by a circuit of 440 volts. Artificial respiration was of no help. Actually, the switch box was part of the fire control circuit and the gunner's mate was not authorized to open it. Even if he thought he was, he certainly should not have forgotten this precaution issued to the ship:

> When work is done on any circuit, the switch controlling that circuit should be opened and a danger sign secured to it.

The danger sign should contain sufficient instructions to prevent anyone but the proper individual from reenergizing the circuit. (Note precautions 1 and 8.)

2. In September 1963, a DD was moored in a nest with five DDs and one AD, third ship outboard, at Newport, R.I. During the morning, extensive system alignment checks were being conducted on the torpedo fire control system in preparation for a test firing of dummy torpedoes the following day. The crew, which was being directed by a Torpedoman's Mate 2, had been working long hours the previous week attempting to get the system in proper working condition for the forthcoming exercises. They had had trouble clearing electrical grounds from the firing circuits of numbers 2 and 4 tubes. While conducting tests during the previous week and that day, it had been necessary for them to remove the torpedo from each tube before firing an air slug electrically, then to reinsert it after firing. One of the torpedoes (the one that had been in number 2 tube) was left on the rack behind the tube. The crew had difficulty clearing the ground from number 2 tube so they decided to switch their efforts to number 4. They corrected the ground in number 4 tube but failed to remove the torpedo. Meanwhile, the ship experienced a shore power failure. This

failure did not stop the work on number 4 tube but did add somewhat to the existing confusion. Finally, after the tube was charged with air, it was electrically test fired by the TM 2 (who forgot number 4 was loaded). Result—the 44 torpedo, which was a warshot, was fired against the superstructure, frame 81, of the DD alongside. Damage to the DD was minor. The torpedo, however, had to be removed from service.

The findings of the Board of Investigation were that:

1. The firing of the torpedo from tube number 4 occurred as a result of personnel error.

2. The temporary loss of ship's power for a period of one hour and ten minutes prior to the incident, coupled with numerous pulling and reinserting of torpedoes from their tubes in the days preceding the incident, were distracting influences which might have "dulled" the attention to detail which a transmission check demands. (Note precaution 8.)

The TM 2 was wrong in what he did, but it appears he could have used some backup supervision. If his leading division petty officer or his division officer had been on deck during this official test of the tube, chances are that the accident would not have happened. They should make it a point to be at the places where work is going on, at the right time. That way they have a much better chance of catching possible trouble sources before it is too late.

MATERIAL DAMAGE: Loss of one torpedo.

3. In 1964, a grenade fuze detonation occurred in an aircraft carrier's fuze magazine, which contained stored fuzes. (Note precautions 12 and 21.)

Two military personnel entered a fuze magazine, whereupon the topic of conversation turned to grenade throwing. One of the men picked up a grenade fuze and proceeded to demonstrate the hand launching method. While going through the motions of hand launching, the grenade fuze activated. Realizing what had happened, an attempt was made to kick the fuze under a storage bin. Detonation occurred, causing multiple wounds, punctures, and lacerations to the two military personnel. Fortunately the blast was not of sufficient magnitude to activate the stored material.

INJURED:	MATERIAL DAMAGE:
Two	None

4. In April of 1963, at a Naval Auxiliary Air Station, a fixed-fin air-launched rocket was inadvertently fired after checkout and arming. An aircrewman, upon completing a stray voltage check of launcher control circuits, placed the selector switch on station number one. Rockets were then installed and the rocket motors armed.

Without warning, the number six position rocket inadvertently fired. Fortunately, a malfunction occurred and the rocket motor exploded after only traveling about 200 yards. The only damage sustained was to the rocket itself plus a slight injury to the left forefinger of the aircrewman.

INJURED:	MATERIAL DAMAGE:
One	None

5. Hand grenade fuzes were being stowed away in a small arms magazine aboard a Navy vessel on March 29, 1963, when one accidentally exploded.

The hand grenade fuzes were received in ammo container consisting of various broken lots. Two ordnance men were in the process of stowing the shipment when an explosion occurred.

One ordnance man suffered severe powder burns of the right hand and chest, and amputation of one digit on second finger of the right hand. The other man sustained minor powder burns to his right hand, arm and chest.

The probable cause of the accident, after checking the ammunition container and the detail report from the two personnel, can only be theorized. The accident probably occurred because the pin end of the remaining fuzes was not completely spread and resulted in improper packaging. The improperly packaged fuze ring may have caught on a projection of the storage rack during storing procedures.

INJURED:	MATERIAL DAMAGE:
Two	None

6. During a scheduled night training exercise (in December, 1964) a large multi-engined aircraft was scheduled to drop aircraft parachute flares every eight (8) seconds to properly illuminate the target area. Flares Mk 5 which would normally be employed were not available and flares Mk 24 were substituted; although they were similar, no formal publication had been received by the operating activity concerning their use.

On the flare dropping run the aircraft personnel radioed they had difficulty meeting the

rate of drop and had experienced one or two instances of flare hang up in the sonobuoy launch chute, and instructions were requested. However, the operation was continued. Shortly after, observers saw a brilliant light and burning in the after lower section of the aircraft's fuselage. The aircraft crashed into the sea killing all thirteen (13) persons aboard. The crashed aircraft sank in deep water. Investigation showed the planned training exercise called for an unusually short interval between drops, and no deflector was provided to lessen the ship air stream pressure at the sonobuoy chute outlet. It is believed that a flare jammed in the chute and was inadvertently ignited before it could be cleared from the aircraft.

KILLED:	LOSS:
Thirteen	One airplane

7. After supper, a marine who was out in the field on training maneuvers (March, 1964), took a stroll near his bivouac, and found an unexploded item of dud ordnance. Instead of marking its location and reporting the find to his Commanding Officer in accordance with specific instructions, he picked it up and carried it into a nearby gun emplacement. None of his marine associates in the field maneuvers could readily determine what it was. Soon there was a small group around the ordnance curiosity. When disassembly operations were started, the resulting explosion killed three and seriously injured two.

This incident was determined to be the result of a violation of instructions.

INJURED:	KILLED:	MATERIAL DAMAGE:
Two	Three	None

8. In December 1964, the missile racks of an aircraft were being prepared for loading. The port and starboard missile stations were each checked and the port station was found to be unsatisfactory. The starboard station was found to be operative however, and was thus loaded.

During a continuity check of the port station, the starboard missile fired setting fire to the aircraft. The ensuing fire resulted in serious burns to two personnel and completely destroyed the aircraft.

Since the aircraft was destroyed, one can only assume the cause of the accident. However, it can be said that had both launchers been clear for checkout, this accident would not have happened.

INJURED:	MATERIAL DAMAGE:
Two	One aircraft lost

9. In November 1964, a functional firing test was being performed on a nonrotating variable time fuze. In preparing the fuze for test, two ordnance men had overlooked a booster which should have been removed. The fuze thus ignited during the test and the two men were injured although not seriously. (Note precaution 8.)

INJURED:	MATERIAL DAMAGE:
Two	Slight

10. In April of 1964, a range clearance operation was underway at a Marine Corp. base. A master sergeant assigned to the operation came upon a torching igniter of an impacted dud. He attempted to extinguish the flame with dirt and had apparently succeeded when the igniter exploded. The master sergeant was killed.

DEAD:	INJURED:	MATERIAL DAMAGE:
One	None	None

11. In April of 1963, two ship's personnel were clipping small arms ammunition in the magazine of a ship. As they proceeded about their duties, one of the men removed a hand grenade from a nearby container. Without further regard, he pulled the pin and the grenade detonated in his hand causing injury to him and his companion.

INJURED:	MATERIAL DAMAGE:
Two	None

12. A destroyer had just completed firing a pattern of four Hedgehogs on the morning of 19 January 1950. In his hurry to reload the projector, a gunner's mate apparently neglected to remove the safety plugs from the firing circuit.

An assembly error in the firing circuit caused spigot contacts to be 180° out of phase. At the end of the ripple switch cycle, the circuit for spigot No. 12 was energized continuously. When the gunner's mate placed a charge on this spigot, the charge fired. It blasted the man's hand off up to about one-third of his forearm.

INJURED: 1.

13. In 1952, on the hangar deck of an aircraft carrier, an aviation ordnance man was ordered to overhaul the 20-millimeter guns of a plane. He did not check thoroughly to see that the guns were empty before he started working. One of the guns accidentally fired. Five people were injured, and the belly tank of an F4U was badly damaged.

INJURED: 5.

14. In September 1949, an amphibious landing demonstration was scheduled at a large eastern Atlantic port. Thousands of spectators attended. One part of the program called for a demonstration of demolition techniques. Live explosives were to be used against dummy obstacles. In order to simulate the burst of an antiaircraft projectile, the Ordnance Officer of one demolition team modified Emergency Identification Signals. Their pyrotechnic contents were removed, and a charge of one-half pound of TNT was substituted. A hand grenade detonator was tied or taped to the TNT. The alterations were made without any authorization from the Bureau of Naval Weapons. (Note precautions 4 and 5.)

Only 5 minutes prior to the demonstration, the Commanding Officer and the Executive Officer were told of the substitution. The Ordnance Officer, an experienced man, assured them that the signals had been test fired and were safe for firing. He was given permission to fire the modified signals.

Two signals fired satisfactorily. The third misfired and was removed from the projector. The fourth detonated within the projector, causing it to explode violently. A newspaper photographer was struck by a flying fragment and killed instantly. The Ordnance Officer, fatally injured, died 6 days later. Three others were hurt.

DEAD: 2. INJURED: 3.

15. 6 August 1950. During a primer test of a 3-inch mount in a destroyer, a gunner's mate second class inserted a short shell case containing the primer and ordered the loader motor energized. The gun switch was on BOTH, and the other gun had previously cycled. In this condition, the loader mechanism of the gun on which the gunner's mate was working also would cycle.

Either the gunner's mate was not aware of this fact, or he forgot it. When the loader mechanism cycled, the flexible end of the pivoted chute liner struck him a flat, jolting blow on the head, dislocating and fracturing a cervical vertebra. As a result, the gunner's mate died.

DEAD: 1.

16. 1 July 1952. During a practice run of a destroyer, a member of the gun crew of a 5-inch 38-caliber mount, was seated on the right gun captain's platform. The right gun was not to be fired. The man's left leg was placed beneath the right gun slide. At command, the mount elevated, the breech of the right gun descended and crushed the man's leg. It had to be amputated.

INJURED: 1.

17. On 21 April 1952, a heavy cruiser was engaged in a bombardment of enemy land troops on Korea. No enemy return fire was experienced during the time involved in this casualty. During the forenoon watch, turret one fired 42 rounds, 14 from the left gun. Guns and breech mechanisms were serviced after this firing was completed.

No firing occurred during the afternoon watch. After this watch was relieved, shortly before 1600, the left and center guns of turret one were loaded, ready to resume fire. Control of the 8-inch 55-caliber turret was in PLOT with spotting by a shore fire control party. At 1557, the firing circuit for the first salvo was closed by PLOT. The center gun fired; the left gun did not.

Apparently, no one in the fire control organization, either inside or outside the turret, knew that only the center gun had fired. The commanding officer knew, but he had no reason to think that anything was wrong. An open firing key, a slow load, or several other safe reasons for the left gun not firing could have existed.

No report was received from the turret that the left gun had not fired. Later actions indicate that the gun crew of the left gun apparently believed the gun had fired. The noise, added to the heavy vibrations of an adjacent gun firing, can fool even the most experienced. It is difficult for the crew member charged with observing the recoil-counterrecoil marks to keep from involuntarily closing his eyes as the salvo is fired.

This would not be the first instance in which a gun crew did not realize that its gun had not fired. Salvo latches were first installed many years ago because of the difficulty in knowing whether a particular gun had fired in salvo.

After the spot had been received from the shore party and applied to the range-keeper, the

control officer ordered turret one to reload the left and center guns. The order was acknowledged over the fire control telephone. Further indication that turret personnel believed the left gun had fired, no comment was made by the turret captain when he received orders to "reload" the left gun. This evidence presented to the Court of Inquiry indicates that the casualty had not yet occurred: the turret captain was still alive.

Immediately thereafter, the commanding officer saw "white and some yellowish smoke issuing forth from turret one" and sounded the general alarm. From within the turret, someone shouted to the safety watch outside to open the latches. In a few seconds, a second "explosion" was heard.

When rescue teams finally succeeded in opening the hatches, a thick, choking smoke poured out. Bodies were found piled against the hatches. At the port hatch, for example:

> ". . . there were these people all wedged in the hatch at once and we pushed them up. We tried to pull them out first. We couldn't get them out that way so we pushed them with our feet and they came back down and we pushed them up again and we finally got one man out."

When the turret at last was cleared, 28 men were found dead of suffocation. Several minutes later, the two men still alive when pulled out, died—without saying a word.

The first fire consumed two full charge smokeless powder bags in the chamber of the left gun. The second fire consumed one full charge bag in each of the two upper hoists.

No one ever will know exactly what happened at the left gun just before the first fire, or from then on. All the witnesses died. But from the conditions found within the gun room and the hoists, it seems most probable that the breech of the gun was opened while a hangfire was in progress.

> (The possibility of a serious accident due to opening the breech of a gun too soon in the case of a hangfire demands the constant exercise of the utmost prudence and caution. . . Keep the breech mechanism fully closed.)

These were the conditions found:

1. The breech plug was opened and latched.
2. The gas ejector control valve was closed.
3. A projectile was seated in the gun.
4. The tray was spanned.
5. A second projectile was on the tray, its point-detonating fuze blackened by flame or heat.
6. There was an accumulation of burned powder residue in the left gun chamber.
7. Both upper end covers of the upper powder hoists were open: the left cover was broken.
8. The gun captain's ready switch was at SAFE.
9. The salvo latch was in an operating condition.

To determine just how the accident could have happened, several tests were made. It was found that the firing circuit to the primer could be closed when the breech operating lever was within less than 2 inches from its latched position. The rotary motion of the long breech operating lever closed the firing circuit before actually engaging the salvo latch. This in itself did not create a dangerous condition except as it affected later actions. If the gun had fired immediately, no casualty would have occurred. However, a current OrdAlt changes the arrangement so the lever cannot remain in this position.

At the order to reload, the gun captain apparently opened the breech. (Note precaution 20.) In doing so, apparently the gun captain did not notice that he did not have to release the operating lever catch. He did not realize that anything was wrong until the breech plug had swung down and clear of the breech. If a hangfire was in progress, as seems likely, the gun ejector air—which normally clears the bore of unburned gases—was fanning the flame.

The gun captain must have tripped the lever to cut off the gas ejector. Then, either the intense heat of the burning powder or an instinctive reaction caused him to turn away from the breech—at least momentarily. He may have been calling for the sprinkling system to be turned on.

Somehow, this or some other inadvertent action of the gun captain must have been misunderstood by the trayman as a "bore clear" signal. The tray was spanned; the situation became hopeless. With the tray spanned, it was impossible for the gun captain to close the breech quickly enough to avert disaster. The partly confined powder in the gun chamber became fully ignited and belched flame into the gun room.

Apparently a crew member actuated the foot-pedal system following the "bore clear" signal to open or partly open the upper end covers of the upper powder hoists. With the cars at the upper end of the hoist, two bags of powder were exposed to burning powder grains from the first two charges. Both bags were consumed entirely. Whatever oxygen was left after the first charges burned must have been exhausted by the second two. The men who died suffocated; they were not burned to death.

Several safety precautions, general and specific, were involved in this tragic series of incidents. So far as is known, none of these precautions were violated intentionally. But error built upon error. If the same precautions are not observed on a similar gun, the same results can be expected. Only training and strict observance of every precaution can prevent such accidents.

DEAD: 30.

18. During an advanced battle practice, another foul bore casualty was narrowly averted because of the action of an alert rammerman. The rammerman, stationed in turret four of a battleship, had been thoroughly indoctrinated with the importance of continued observance of the powder chamber and the screwbox as the load was being made.

He detected a burning fragment in the powder chamber as he was ramming the projectile home. The gun captain had not seen the fragment, and he started to open the powder door. The rammerman immediately threw his body across the loading tray and pushed the incoming powder bags back into the upper handling room. The powder door was then closed, and the fragment was put out by the auxiliary gas ejector air jet.

CASUALTIES: None.

19. On 1 October 1951, one 5-inch 38-caliber gun aboard a destroyer fired into another. As a result, 6 men were killed and 15 wounded.

In the investigation that followed, the Commanding Officer and the Gunnery Officer stated that they were unaware that such an accident was possible. If they had known that one gun could fire into the barrel of another, they would have — as prescribed by the general safety precaution A-1 — issued additional precautions intended to prevent such an accident. As it was, no warnings or precautions dealing with this hazard had been posted.

The mount captain had not complied adequately with safety requirements, for he did not use his sight port to observe the line of fire to insure that it was safe. The gun of mount two, the mount hit, was trained and elevated to a "ready" position. In this position, the gun barrel could be in the line of fire of mount one. Mount two was not firing; it was not to fire until after mount one had completed its firing. For safety, therefore, mount two should have been held "ready" at its normally secured position "ready," degrees train. If it had been held "ready," no accident would have occurred.

The cut-out cam is designed to prevent firing into fixed objects of the ship's structure. These include turrets, mounts, launchers, torpedo tubes, and cranes in their stowed position only. Personnel must see that such items do not endanger the line of fire. In this case, any one of several responsible individuals — the Commanding Officer, the Gunnery Officer, the Control Officer, the mount captain, or a safety observer — could have prevented the accident. No mechanical defect existed. The failure was human.

At the time of this casualty, safety precaution A-52 (precaution 32 in this appendix) read:

> When using director train while firing at gunnery exercises, an observer from the firing vessel for each gun or turret shall cause the firing circuit to be broken whenever the gun or turret is trained dangerously near any object other than the designated target.

This precaution has been revised to its present form, to remove any possible doubt as to its meaning. The change was made partly as a result of this accident.

DEAD: 6. INJURED: 15.

20. In September 1944 a violent blast wiped out a naval ammunition depot. The Chief of the Bureau of Ordnance stated that the explosion resulted from "accidentally dropping or otherwise roughly handling a depth bomb."

According to eyewitnesses, a depth bomb was being transported on a standard two-wheeled

stevedore truck. Apparently, because of carelessness, the bomb fell from the truck and exploded. One end of the depot became enveloped in flames. It spread to loaded charges in the building, but enough time elapsed to allow most personnel to escape. A huge blast then took place, blowing up the depot and its adjacent facilities. (Note precautions 8 and 12.)

DEAD: 10. INJURED: Over 60. MATERIAL DAMAGE: Destruction of depot.

21. On 12 June 1952, drill projectiles were being sent up the hoist of a transport during a supply drill for 5-inch 38-caliber guns. The projectile hoist suddenly failed. It would not hoist from the handling room to the mount. The mount captain opened the hoist and placed his right hand on the butt end of the projectile and his left hand on the ejector lever. He proceeded to twist the projectile in order to see if the fuze setting lugs were correctly engaged in the fuze pot.

The hoist operator thus said that the hoist manual lever was stuck, at the same time placing his hand on that lever. The hoist cycled. The index and middle finger of the mount captain's right hand were shorn off.

A notice plate just above the door read DO NOT PLACE HAND IN HOIST. Instruction specified that power *must* be secured before any adjustments are attempted. (Note precaution 1.)

INJURED: 1.

SUMMARY

The following report of a Navy board clearly expresses the lesson this appendix strives to emphasize:

"It is unquestionable that any intelligent action in prevention of casualties must be based on a thorough knowledge and understanding of safety precautions. All personnel concerned must thoroughly understand how and why (safety precautions) actually apply in practice, as well as have a knowledge of what (safety precautions) are. Constant vigilance must be exercised to assure that they are at all times carried out in every detail; any violations or tendency to veer from this vigilant attitude must be abruptly checked at the time it occurs.

Inasmuch as the safety precautions are generally understood by all hands to be one of the primary laws of self-preservation, cases of willful violation of them are rare. It is, rather, ignorance of their existence and application, or a slacking off of their meticulous observation bred from an overconfidence in nonoccurrence of casualties, that causes violation of them.

There can be no law against casualties nor can they be ordered out of existence. This can obviously not be done under conditions where the human element is involved. However, a large percentage of casualties can be very definitely and positively eliminated by a proper overhaul, inspection, and test of material and by proper and sufficient drill of personnel in handling their gear."

INDEX

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